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COMPARISON OF AIRCRAFT AND ACOUSTIC

SOUNDER TEMPERATURE-INVERSION DATA

AT THE C-b TRACT
March 30, 1976

Prepared By

Spencer A. Bullard
Consulting Engineer
and
George E. Fosdick
Senior Environmental Engineer,
C-b Shale Oil Project

For

C-b Shale Oil Project
Shell Oil Company, Operator
1700 Broadway
Denver, Colorado 80202

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FOREWORD

This report analyzes quarterly temperature soundings obtained from aircraft and acoustic sounder records regarding frequency and height of air-temperature inversions. The study encompasses the scope, purposes, data description, and data analyses. The overlapping data period consisted of three fifteen-day periods in the winter, spring and summer of 1975.

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Marlatt and Associates, consultants from Fort Collins, Colorado, have supplied the basic data and interpretation for the acoustic sounder in this report under contract to the C-b Project. Their principal analysts have been Dr. William E. Marlatt and Mr. Edward A. Howard.

1. SCOPE

1.1 Scope:

This report presents analyses of upper-air temperature-inversion-height measurement methodology and compares acoustic-sounder temperature-versus-altitude traces obtained by direct measurement with aircraft.

The scope is intentionally limited to data comparison over the three 15-day, aircraft flight periods which overlapped with acoustic-sounder operation in 1975. Specifically this report does not include the following:

- a. It does not provide data on all inversion heights during the baseline.
- b. It does not provide data on all mixing-layer heights nor a technique to obtain same.
- c. It does not address the problem of representativeness of the aircraft data.
- d. It does not address the problem of obtaining atmospheric stability classes or associated parameters.
- e. It does not incorporate meteorological tower data at the Tract.

1.2 Purpose:

The purpose of this report is to evaluate by comparison with direct temperature measurement the acoustic-sounder capability to provide reliable data on a continuous basis of temperature inversion occurrence and height for the C-b Tract.

1.3 Summary:

Temperature versus altitude plots were derived from direct, vertical temperature profiles obtained from aircraft flights over the C-b Tract for 15 days for each of the first three quarters of 1975. Four flights were attempted on each day. At the same time continuous monitoring of upper air temperature characteristics was accomplished by acoustic-sounder instrumentation. The temperature-versus-altitude plots are used in this study to compare acoustic-sounder signatures which indicate height of both stable and unstable layers.

Collection methodology, data quality, and characteristics of air-inversion data are discussed as are presentation and interpretation of the data.

Emphasis is placed on a statistical comparison of two measurements of occurrence frequency and height of inversion. Height and frequency

of temperature inversions are important for modeling and prediction of the impact of shale-oil mining operations on air quality.

Statistical analyses show that the range of agreement between acoustic-sounder estimates of the existence and height of inversions with that obtained by direct measurement by aircraft is between 75 and 90 percent.

Sources of error contributing to the lower-than-expected level of agreement are 1) the difficulty in interpreting acoustic-sounder data as a major, limiting factor; 2) accurate determination of time on the acoustic-sounder strip charts due to variations in chart speed; 3) a constant speed on sound is assumed in the sounder to relate time of echo return to height inducing about a 3 percent error; 4) a lateral displacement of about 1 kilometer exists in the ascending aircraft helical profile; 5) the atmosphere is dynamic and changes somewhat over the time required for the temperature profile by the aircraft.

Relative advantages accruing from use of the aircraft are the relative ease of interpretation of the data and provision of the entire thermal profile to 13,000 feet elevation. The sounder, on the other hand, provides 24-hour, continuous data collection, a near-instantaneous response, and relatively low cost of operations. Both systems proved a valuable adjunct to each other.

2. APPLICABLE DOCUMENTS

All documents relevant to understanding and defining data in this report have been specifically referenced by number in the text and identified in the Reference Section.

3. THE DATA

This chapter describes the data, collection methodology, presentation format, data interpretation, and data quality for both acquisition techniques.

3.1 Aircraft Data:

The upper air temperature-soundings program was performed for the C-b Shale Oil Project by EG&G Environmental Consultants over the course of four intensive 15-day quarterly periods during 1974 and 1975. The measured data consisted of ambient temperature soundings from about 6,300 feet to 13,000 feet above MSL* with values recorded at 100 foot increments. The fall study was performed from October 1, 1974 to October 15, 1974. The winter study was performed from January 20, 1975 to February 9, 1975. The spring study was performed from April 14, 1975 to May 1, 1975. The summer study was performed from July 12, 1975 to July 26, 1975. Because of safety considerations, some soundings were cancelled due to inclement weather conditions.

During each intensive period, four soundings per day were attempted to investigate the formation and breakup of inversions. During the fall

*Mean Sea Level

1974 study, inclement weather forced cancellation of the flights on seven of the 15-study days. The operational plans were changed therefore for the remainder of the seasonal studies. Cancellation of the soundings on any particular day due to either instrument problems or inclement weather forced another day to be included in the schedule at the end of the planned study period. This effectively ensured that the study obtained data for a minimum of 15 days. For the winter, spring, and summer studies, a successful sounding day was defined as one for which a minimum of two temperature profiles were obtained with at least one of these extending into the canyons below the tract surface.

3.1.1 Collection Methodology:

The vertical, temperature structure from the surface to 13,000 feet (MSL) was determined four times per day with a sensitive, shielded thermistor mounted on the wing strut of a light aircraft. The four flights were made at approximately 0500, 0800, 1100, and 1700 hours, MST. Soundings were made to within 100 feet of the surface during each day when safety considerations permitted. Flights were also made in the Piceance Creek Valley at 0500, 0800, and 1100 hours MST to determine the temperature structure of the air at elevations lower than the Tract.

Temperatures were recorded with an EG&G Model 702 Portable Temperature Recorder which is designed to achieve high-resolution temperature recordings from a moving vehicle.

During the 0500, 0800, and 1100 MST soundings over Tract C-b, the flight path called for a slow, gradual ascent from approximately 50 feet above the surface of the Piceance Creek (in the direction toward Tract C-b and the meteorological tower) to an actual top-of-tower fly-by. This required that temperature measurements be made at a level comparable with the elevation of the base of the tower but horizontally displaced from the tower itself. On a typical flight path the temperature measurement at the base of the Tract C-b tower was made approximately 1 km to the north. Because of this, data below 7,200 feet cannot accurately be termed "vertical" temperature soundings, even though the 10 feet-per-second rate of ascent was maintained along the near-horizontal flight path. Once the tower-top fly-by check of the altimeter setting was made, the aircraft began its normal ascent to 13,000 feet in an approximately 3000-foot diameter spiral at a rate of about 10 feet-per-second. Altitude markings were made on the temperature chart in real time. The pilot attempted to maintain a constant rate of ascent which was not always possible because of turbulence. For this reason, temperature and altitude readings were taken from the charts only at points marked with a distinct altitude. No interpolations between markings were used.

3.1.2 Data Quality:

To assure quality control of the upper air studies EG&G Environmental Consultants have utilized the following procedures:

- a. The EG&G, Model 702, Portable, temperature, recorder unit was calibrated to within $\pm 0.2^{\circ}\text{F}$.
- b. The flight path of the aircraft was duplicated as closely

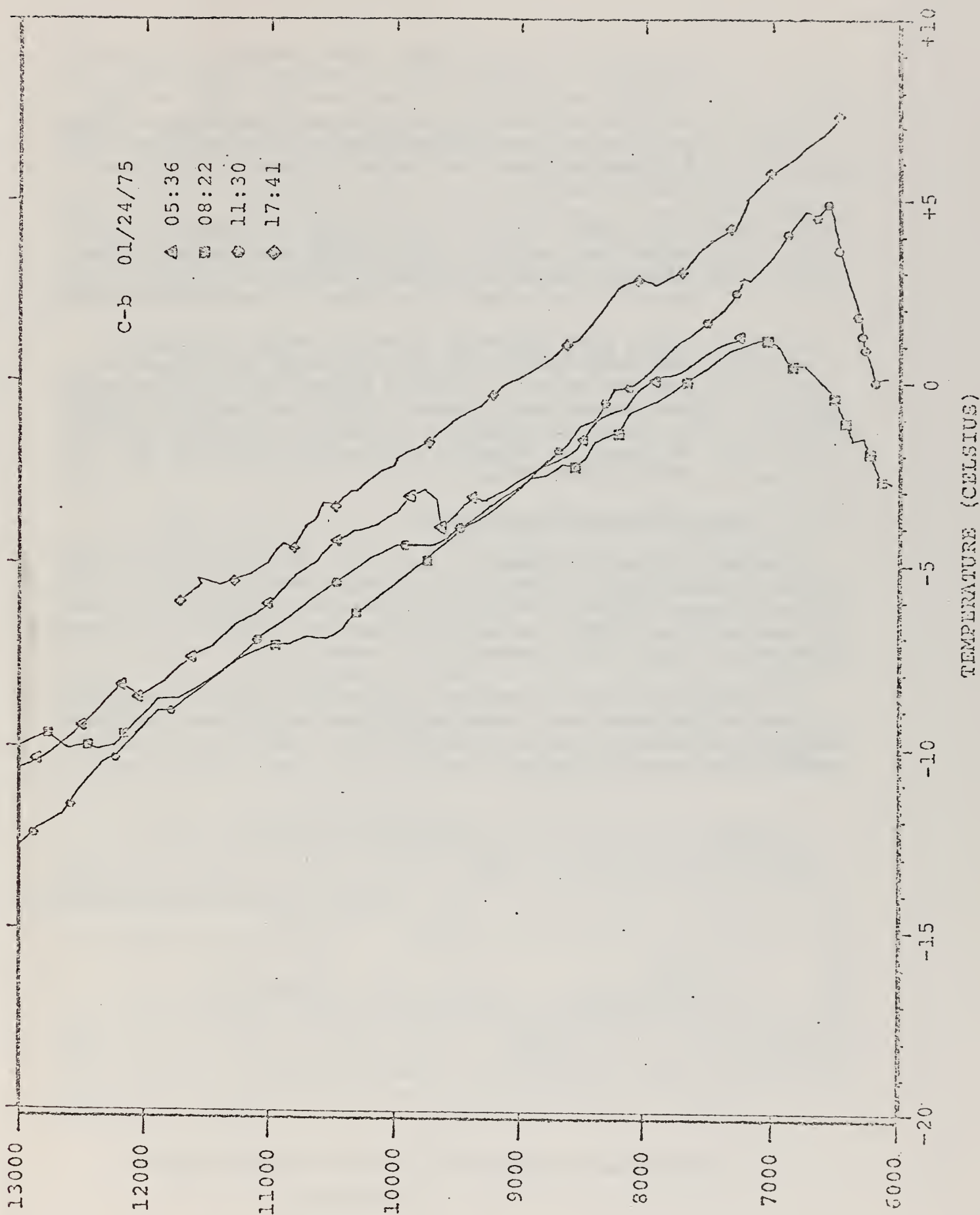


Figure 3.1-1 Typical winter temperature profile.

as possible for each flight. When possible, the aircraft was flown to 200 feet above the surface at the tower, an altitude corresponding to the tower top. This was done to verify the accuracy of the aircraft altimeter settings; in all cases the altimeter indicated an elevation of 7200 $\pm$ 50 feet above mean sea level (MSL) for this 7200 foot actual elevation.

- c. The aircraft normally flew in a 3000-foot diameter spiral around the tower to 13,000 feet MSL obtaining data every 100 feet in a normal 10 feet/second rate of climb. Thus there is this lateral displacement in the vertical sounding.
- d. Actual times indicated for each sounding correspond to "tower fly-by's" at 200 feet above the surface. At an approximate rate of climb of 10 feet/second, the sounding over an altitude increment of 5800 feet took 580 seconds or 9 minutes 40 seconds, so that the temperature profile represents an average over this time interval in a dynamic atmosphere.

3.1.3 Presentation and Interpretation:

The basic data of references 1, 2, 4, 5, 7, and 8 are presented as plots of altitude versus temperature, typically shown on Figure 3.1-1. All basic data plots are presented in Appendix A as Figures A-1 through A-37 with a table of inversion altitudes from both aircraft and sounder added, as in Figure A-3 corresponding to Figure 3.1-1.

In addition, reference 9 presents mixing-layer height information, utilizing a fictitious stack height of 300 feet, as follows. Points H_1 and H_2 used in the analysis are defined in the idealized temperature profile illustrated in Figure 3.1-2.

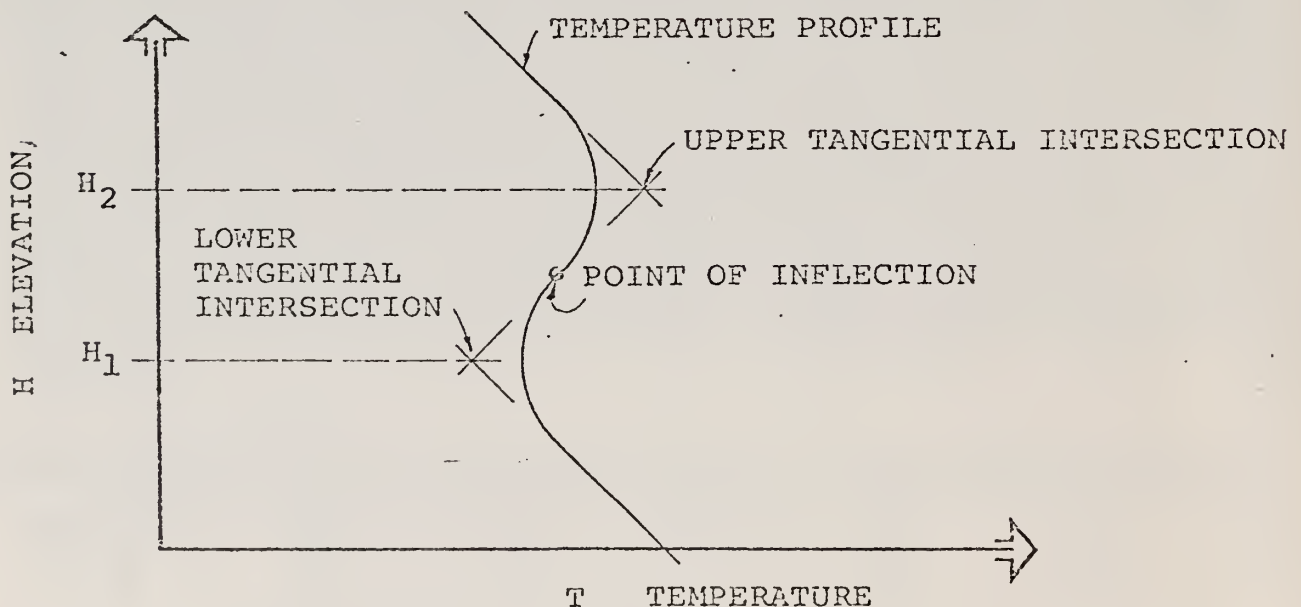


Figure 3.1-2
Detailed Temperature Profile (Idealized Inversion)

Several unique cases involving the relationships between H_1 , H_2 , and stack height, S , exist as shown graphically in Figure 3.1-3. Tables 3.1-1 and 3.1-2 present the values of H_1 and H_2 measured for all soundings made throughout the annual period; fall 1974 data are included for completeness. Because the level used to reference H_1 and H_2 was chosen at 7000 feet above MSL (elevation of proposed plant site), it is possible to obtain negative values for H_1 and H_2 . This could only happen when the significant temperature structure of interest was contained entirely within the valleys below the level of the tract.

It should be pointed out that the mixing layer heights reported are not necessarily the heights of only surface-based inversions, but reflect altitudes of elevated inversions as well. To ensure that only significant mixing layers were included in the average height determination in reference 9, an inversion was required to be at least two hundred feet deep with a total temperature change of at least 1°C from top to bottom of the interval; the present report relaxes this as stated later.

An example should serve to clarify the classification technique used for determining H_1 and H_2 . Using Figure 3.1-1, the elevated inversion during the 05:36 MST sounding between 2600 and 2900 feet above the reference level (9600 and 9900 feet above MSL respectively) falls into Case I (Figure 3.1-3) and the mixing layer height assigned was 2600 feet. The 08:12 MST sounding showed no evidence of a temperature structure like that in Figure 3.1-2. In this case, H_1 is undefined and H_2 is only 100 feet above the 7000 foot level. Because a 300-foot stack would release emissions above this layer, the mixing layer was deemed non-existent and no contributions to the average height were made for this sounding. The 11:30 MST sounding is similar to that just discussed, except that it lies entirely below the level of the plateau. In this case H_1 is undefined and H_2 is -400 feet.

It needs to be emphasized that H_2 , the intersection of the lower stable layer with an upper, unstable layer, is that point most-readily depicted by the acoustic sounder; most often, H_1 is not clearly defined by the sounder.

3.2 Acoustic Sounder Data:

Acoustic sounders have alternatively been called acoustic radars, sodar (for sound detection and ranging), and acdar (for acoustic detection and ranging). Acoustic energy that is propagated through the atmosphere is scattered by turbulent fluctuations in temperature and wind velocity (reference 12). Reference 13 sums up the principles of acoustic sounding as follows:

"Acoustic sounding involves transmission of sound waves, a

FALL, 1974

WINTER, 1975

DATE	Sounding				DATE		Sounding			
	#1	#2	#3	#4			#1	#2	#3	#4
October 1, 1974	h1	--	--	--	January 20, 1975	h1	msg	1200	--	--
	h2	--	--	--		h2	msg	1600	-500	800
October 2, 1974	h1	--	--	--	January 23, 1975	h1	--	-500	--	--
	h2	500	--	--		h2	1700	1500	--	--
October 3, 1974	h1	--	--	msg	January 24, 1975	h1	2600	--	--	--
	h2	800	--	msg		h2	2900	100	-400	--
October 7, 1974	h1	--	--	--	January 25, 1975	h1	msg	--	4300	--
	h2	--	--	--		h2	msg	--	4600	--
October 8, 1974	h1	--	--	--	January 26, 1975	h1	1900	750	1600	--
	h2	--	--	msg		h2	2400	2100	2100	--
October 9, 1974	h1	--	--	--	January 29, 1975	h1	--	--	3800	--
	h2	1300	--	--		h2	--	150	4200	--
October 10, 1974	h1	--	--	--	January 31, 1975	h1	msg	msg	--	--
	h2	350	450	--		h2	msg	msg	--	--
October 11, 1974	h1	--	--	msg	February 1, 1975	h1	msg	--	--	--
	h2	1000	100	msg		h2	msg	-200	--	--
October 13, 1974	h1	msg	msg	4800	February 2, 1975	h1	2600	--	--	--
	h2	msg	msg	4900		h2	3000	200	-500	--
October 14, 1974	h1	--	--	--	February 3, 1975	h1	--	--	--	--
	h2	--	--	--		h2	--	200	100	--
October 15, 1974	h1	--	--	--	February 4, 1975	h1	--	--	--	msg
	h2	--	600	--		h2	--	--	--	msg
			-600	--	February 6, 1975	h1	--	--	-600	--
						h2	900	800	50	--
					February 7, 1975	h1	msg	msg	--	--
						h2	msg	msg	--	--
					February 8, 1975	h1	--	--	--	--
						h2	--	--	--	--
					February 9, 1975	h1	--	--	msg	msg
						h2	--	--	msg	msg

Table 3.1-1 Fall/Winter H₁ - H₂ Data

msg - indicates that sounding was not made
 --- - indicates that H₁ or H₂ was undefined

SPRING, 1975

SUMMER, 1975

DATE		Sounding				DATE		Sounding			
		#1	#2	#3	#4			#1	#2	#3	#4
April 14, 1975	h1	--	--	--	--	July 12, 1975	h1	--	--	--	--
	h2	--	--	--	--		h2	500	--	--	--
April 15, 1975	h1	--	--	--	--	July 13, 1975	h1	--	--	--	--
	h2	--	--	--	--		h2	100	--	--	--
April 16, 1975	h1	--	--	--	msg	July 14, 1975	h1	--	--	--	--
	h2	--	--	--	msg		h2	200	--	--	--
April 18, 1975	h1	msg	msg	--	--	July 15, 1975	h1	--	--	--	--
	h2	msg	msg	--	--		h2	200	--	--	--
April 19, 1975	h1	5500	5400	500	--	July 16, 1975	h1	--	--	msg	msg
	h2	5800	--	--	--		h2	-150	--	msg	msg
April 20, 1975	h1	--	--	--	--	July 17, 1975	h1	-50	--	--	--
	h2	200	00	--	--		h2	00	-450	--	--
April 21, 1975	h1	--	--	--	--	July 18, 1975	h1	--	--	--	--
	h2	1600	--	--	--		h2	1050	--	--	--
April 22, 1975	h1	--	--	--	--	July 19, 1975	h1	--	--	--	msg
	h2	200	--	--	--		h2	1100	--	--	msg
April 23, 1975	h1	--	--	--	--	July 20, 1975	h1	--	--	--	--
	h2	100	--	--	--		h2	800	--	--	--
April 24, 1975	h1	--	2900	--	--	July 21, 1975	h1	--	--	--	--
	h2	00	3150	--	--		h2	-100	-350	--	--
April 25, 1975	h1	--	3500	msg	msg	July 22, 1975	h1	--	--	--	--
	h2	--	3950	msg	msg		h2	800	--	--	--
April 28, 1975	h1	--	--	--	msg	July 23, 1975	h1	--	--	--	--
	h2	-50	--	--	msg		h2	800	--	--	--
April 29, 1975	h1	--	--	--	--	July 24, 1975	h1	--	--	--	--
	h2	--	--	--	--		h2	1000	--	--	--
April 30, 1975	h1	--	--	--	--	July 25, 1975	h1	--	--	--	--
	h2	--	--	--	msg		h2	1000	--	--	--
May 1, 1975	h1	400	-100	--	msg	July 26, 1975	h1	--	--	--	msg
	h2	--	--	--	msg		h2	1050	00	--	msg

Table 3.1-2 Spring/Summer H1 - H2 Data

msg - indicates that sounding was not made
 -- - indicates that H1 or H2 was undefined

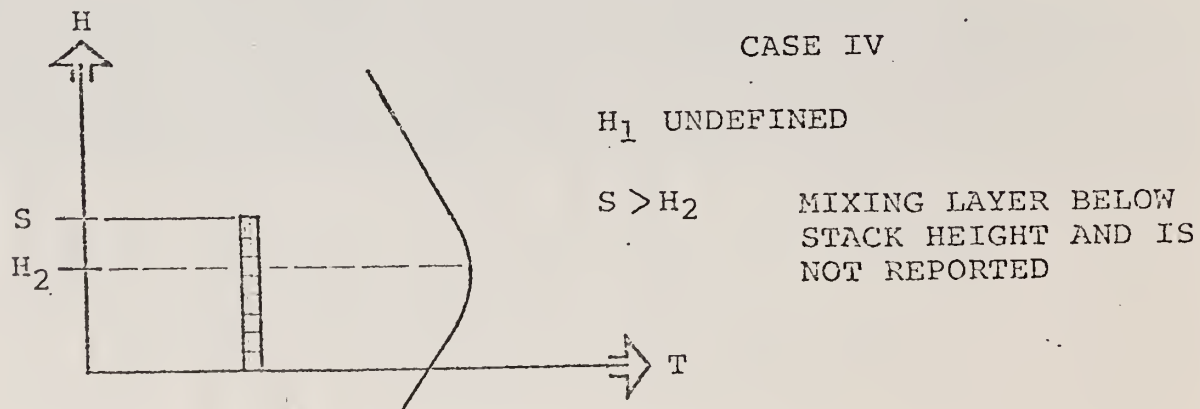
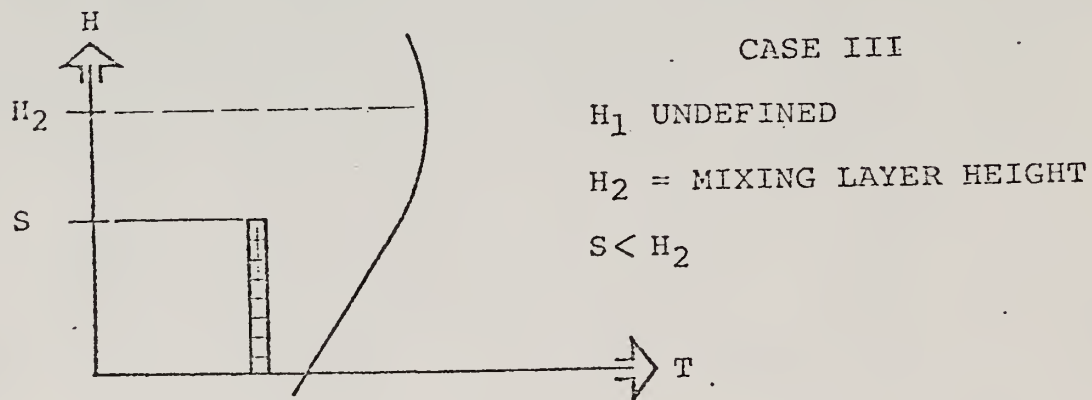
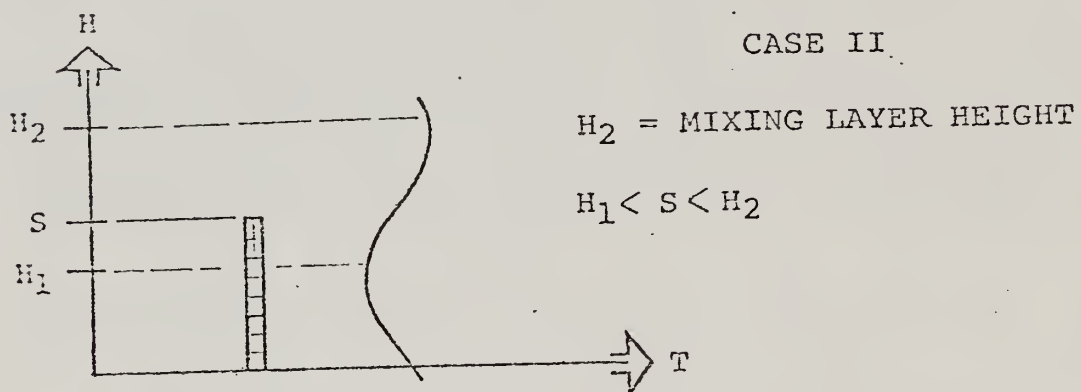
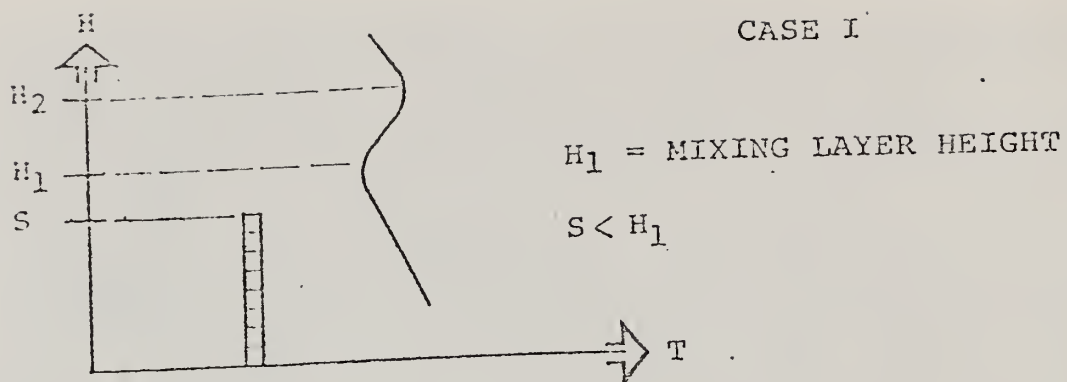


Figure 3.1-3 Mixing Layer Determinations.

scattering of these from irregularities of this atmospheric acoustic refractive index, and reception of the echoes at a ground based station. Theory has shown that when the transmitter and receiver are coincident (monostatic system), the backscattered energy is dominately a function of the spatial variations of temperature. If the transmitter and receiver are separated and the sound follows an oblique path (bistatic system), the acoustic scattering is also a function of the spatial variability of the wind fluctuations. . . "

Reference 14, in slightly different form, sums it up this way:

"Sound energy that is directly back-scattered (180° from the direction of the incident wave) is solely the result of temperature fluctuations in the scattering volume. Acoustic energy scattered in all other directions (except at 90° to the incident beam, where no scattering occurs) is the result of the combined effect of wind and temperature fluctuations.

This angular dependence of the scattering mechanism is of paramount importance to the operation of a sounder. For a monostatic configuration (co-located transmitter and receiver; scattering angle of 180°), one observes echoes that depict the temperature structure constant, C_T , in the atmosphere. With neutral static stability, C_T values are very low, and the scattered energy will be undetected. If a facsimile recorder is used to display the echo intensity, where each sweep of the recorder corresponds to the time required for a single sound pulse to traverse the region of interest, the record will be white when no echoes are received. As the lapse rate changes from adiabatic (either more stable or less stable), any mechanical turbulence in the air will create small-scale temperature eddies capable of backscattering some of the incident sound, and the facsimile record will be darkened in proportion to the strength of the turbulence. The monostatic sounder, therefore, gives an indication of each change in lapse rate or dynamic stability along the path of a transmitted sound pulse, producing a record with a striking amount of contrast and showing considerable detail related to the thermal structure. . . "

3.2.1 Collection Methodology:

The specific acoustic sounders at Tract C-b are co-located with the air-quality trailers at stations 023 (at the meteorological tower) and 021 (at Rock School in Piceance Creek Valley). The specific instrument is the Aerovironment, Model 300, Acoustic Radar as described in Appendix B; for this instrument reference 12 states that the acoustic energy is generated by the white transducer (see illustration in Appendix B) above the circular antenna and transmitted downward through the cone and reflected into the atmosphere in the form of a narrow beam by the

parabaloidal, antenna dish. The path of acoustic energy is reversed for receiving the echoes of scattered sound with the transmitter now acting as a microphone.

The acoustic-sounder program is being performed for the C-b Shale Oil Project by Marlatt and Associates of Fort Collins, Colorado. The sounder at station 023 has been operational since December 6, 1974; that at station 021 has been operational since July 17, 1975. Continuous data have been obtained, except during periods of malfunction, from strip-chart recorders. The recorder principals-of-operation (reference 12) are as follows: The recorder contains a stylus which is drawn across special paper and which makes a mark whose intensity is related to magnitude of the received signal. The stylus starts at bottom of the paper when the pulse is transmitted and reaches the top when echoes from the desired full-scale range have been received. Height of the trace indicates round trip travel time of an acoustic wave between the antenna to the scattering region. Full scale on the trace is equivalent to a height of 1000 meters. Data have been interpreted from the sounder records in half-hour intervals for signatures characterizing inversions. Interpretation of sounder records is somewhat difficult and is addressed in section 4.1; signature examples also appear in Appendix B.

3.2.2 Data Quality:

The following items relate to quality of the sounder data:

- a. Daily time-check manual entries have been made on both sounder strip charts since January 23, 1976. Prior to this time, chart start-of-roll times and end-of-roll times were manually recorded; sounder-chart times have been linearly corrected for chart speed error via their use. After such correction, the spring 1975 data were examined on Table 3.2-1 as follows: the aircraft tower fly-bys often yield a dark vertical-line trace on the acoustic-sounder record at the exact time of fly-by, provided the aircraft passes directly over the sounder. (However, if the first pass misses the vertical sounder acoustic path and the second pass flies directly over, the second would be recorded on the trace.) Thus the corrected time of the fly-by indicated on the acoustic-sounder chart can be compared to the recorded time of fly-by in the aircraft. The range of the time increment (aircraft minus sounder) for those passes yielding a trace was -37 to +29 minutes; mean difference was -8 minutes. Some inversions rose or fell at about 300 meters per hour, so a half-hour increment would be equivalent to a 150-meter ($\approx$ 500 feet) increment.
- b. Sounder operating efficiency for station 023 (which has been operational since December 6, 1974) up to mid-September

Table 3.2-1
Times of Aircraft Tower Fly-By's
vs. Those Indicated on Sounder Chart
(Spring '75)

Date	Time (MST)		Δt (min.) 2 - 3
	Aircraft Tower Fly-By	Indicated on Sounder Chart*	
4-14	0530	0555	-25
	1131	1145	-14
4-15	0515	0515	0
4-16	0838	0838	0
4-18	1138	1145	-7
	1728	1805	-37
4-19	0828	0845	-17
4-20	0527	0550	-23
	0831	0855	-24
	1745	1738	+7
4-21	0540	0615	-35
	1128	1150	-22
	1738	1720	+18
4-23	1724	1655	+29
4-24	0528	0545	-17
	0827	0825	+2
	1147	1145	+2
4-28	0527	0545	-18
	1127	1120	+7
5-1	0815	0815	0
	1112	1110	+2

Range:
-37 to +29 minutes

Mean Difference:
-8 minutes

*Note:

- 1) Aircraft tower fly-bys often yield a dark-line acoustic trace on the sounder chart, provided the aircraft passed directly over the sounder. These traces are credited here in column 3 as the time of fly-by at tower altitude at the times indicated on the sounder chart.
- 2) Sounder chart indicated times have been linearly corrected for chart-speed error by knowing end-of-roll and beginning-of-roll times which were manually recorded.

1975 is as follows:

200 operating days
84 non-operating days
284 total

$$\frac{200}{284} \times 100\% = 70.4\%$$

This efficiency is expected to increase with the daily checks instituted on January 23, 1976.

- c. A constant speed of sound based on surface temperature is assumed when scaling acoustic-sounder records. Reference 14 estimates that this induces 3% error in height indications.
- d. Snow accumulating on the exposed dish causes equipment malfunction.
- e. "Fuzziness" of the trace records indicating the top of the inversion layers can be as much as 50 meters (163 feet) in width.
- f. For purposes of this report, inversions can be compared only up to the limit of the sounder record - 1000 meters (3280 feet).

3.2.3 Presentation and Interpretation:

Basic sounder records of the type illustrated in Appendix B for the period of comparison of the study are on file at the C-b project office. Basic data for the period of comparison - height of the top of the inversion layers at the time the aircraft soundings - are presented in tabular form as insert tables on the aircraft-sounding plots (Figures A-1 through A-37).

Interpreted data regarding inversion duration, inversion minimum, average and maximum height, and inversion statistics appear in references 3, 6, 9, and 11.

4. ANALYSES

This section presents a signature analysis for the acoustic sounder and statistical analyses of the sounder and aircraft air-temperature inversion data.

4.1 Acoustic-Sounder Signature Analysis:

Reference 12 offers the following helpful hints regarding interpretation of sounder records:

- a. The dark band across the bottom of the trace represents

the transmitted signal; the narrower clear space is a delay before the receiver is turned on; the darker areas above represent echo returns.

- b. Echoes with a horizontal type structure indicate a stable stratification; the top of this signature pattern is the top of the inversion.
- c. Echoes with a vertical type structure indicate unstable stratification. When such are ground based they extend upward from the base of the chart.

For April 21, 1975, Figure 4.1-1 shows a typical acoustic-sounder record at Tract C-b for station 023. Segments b-b¹, d-d¹, f-f¹ are ground-based inversions; a-a¹, c-c¹, e-e¹ are elevated stable layers. The stable layers which existed on this portion of the trace from 0200 MST to 0930 yield to instability after 0930 MST.

Three of the four aircraft (a/c) soundings of the same day are plotted on Figure 4.1-2 to the same ordinate (height) scale as Figure 4.1-1 and the composite presented on Figure 4.1-3. Regarding the 0540 MST sounding on Figure 4.1-3.

point a at the top of the surface-based, inversion layer of the a/c corresponds to point a¹ of the sounder trace; point b at the bottom of the elevated stable layer (a/c) corresponds to the bottom of the dark wavy trace on the sounder at b¹; the top of the elevated stable layer, c (a/c), corresponds to that of the sounder at c¹.

For the 0839 MST sounding the top of the weak surface-based inversion at d on the a/c sounding corresponds to d¹ on the sounder trace. The 1128 MST sounding on Figure 4.1-2 indicates completely unstable conditions at all elevations within sounder range, as reinforced on Figure 4.1-3 by the vertical structure of the sounder signature around 0930 MST and thereafter. In summary, the sounder for the 0540 MST flight did correctly indicate the top of the surface-based layer and the thickness, top, and bottom of the elevated stable layer; for 0839 MST it indicated the top of the surface-based inversion layer; for 1128 MST it correctly indicates completely unstable conditions.

Classification of sounder records has been attempted in reference 13 according to some 14 categories coded in half-hour intervals; table 1 of that reference has been incorporated herein as Table 4.1-1. Attempts were made to correlate acoustic-sounder classification with wind speed, wind direction turbulence, and temperature difference. Considerations such as these would be an invaluable extension of the present study. Tests of uniqueness and universality of a (or any, for that matter) classification system are badly needed.

4.2 Statistical Analyses:

Statistical analyses of aircraft and acoustic-sounder upper air data

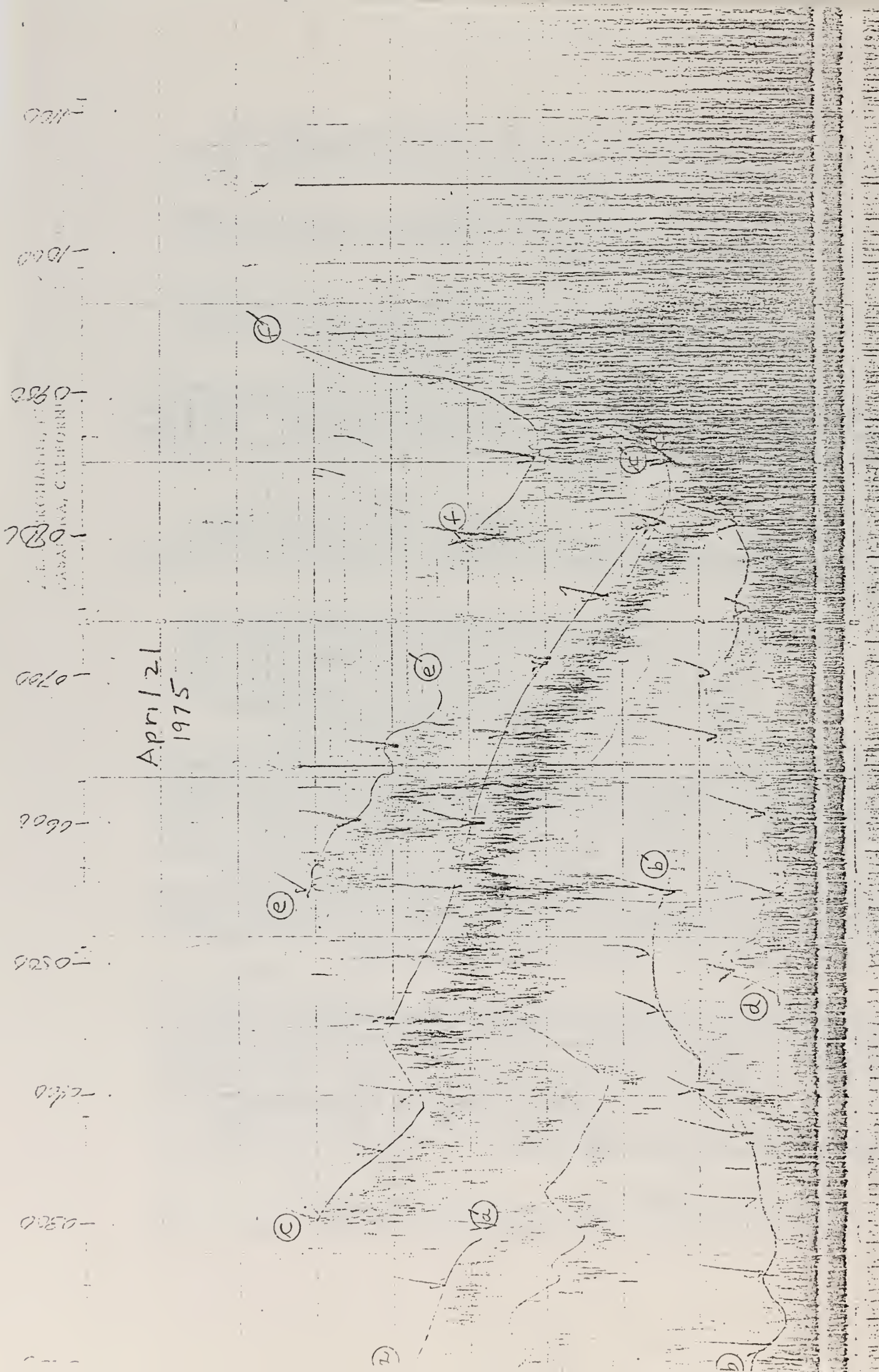
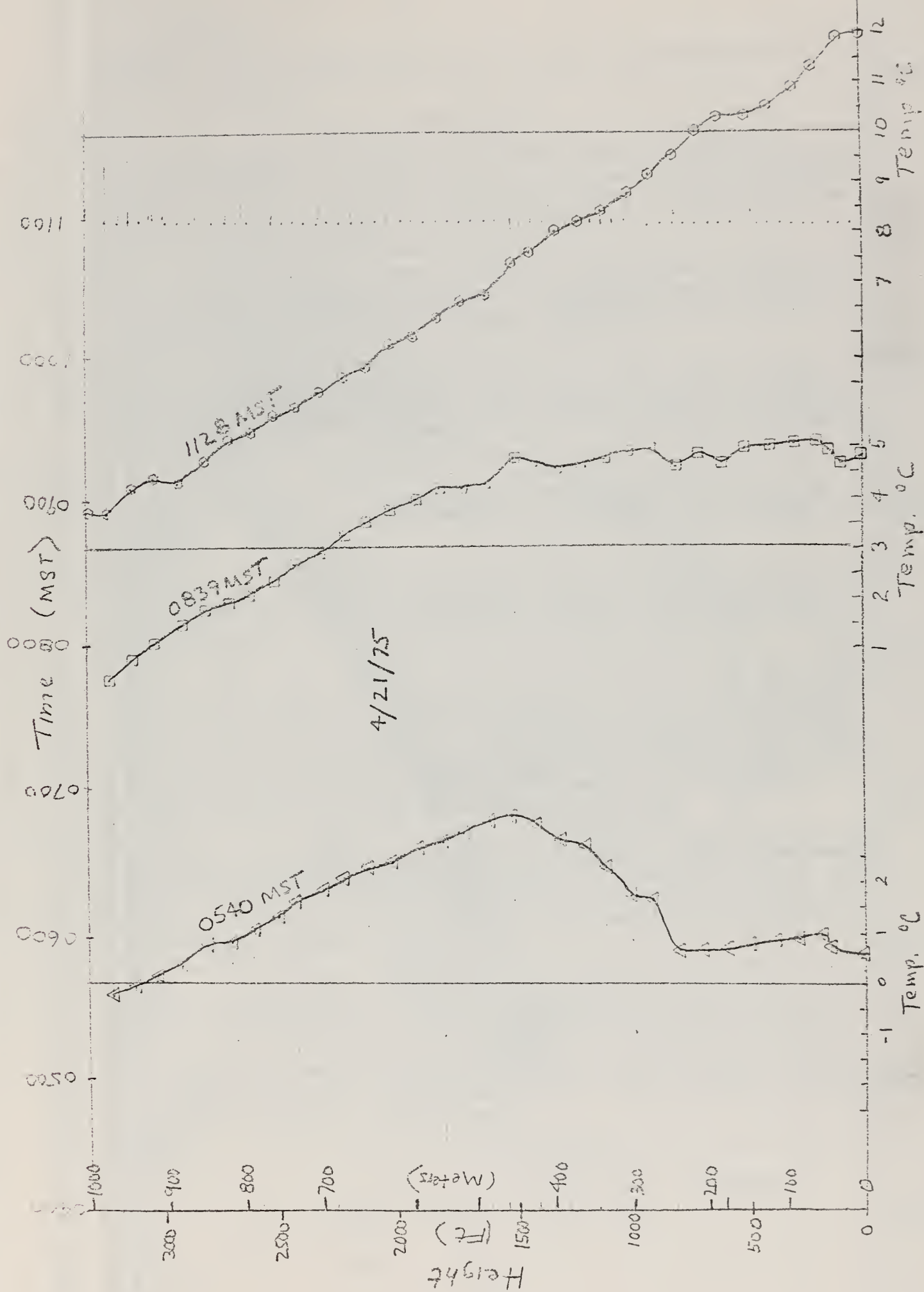


Figure 4.1-1 Typical Acoustic Sounder Record at Tract C-b for April 21, 1975

Figure 4.1-2 Aircraft Temperature Soundings at Tract C-b for April 21, 1975



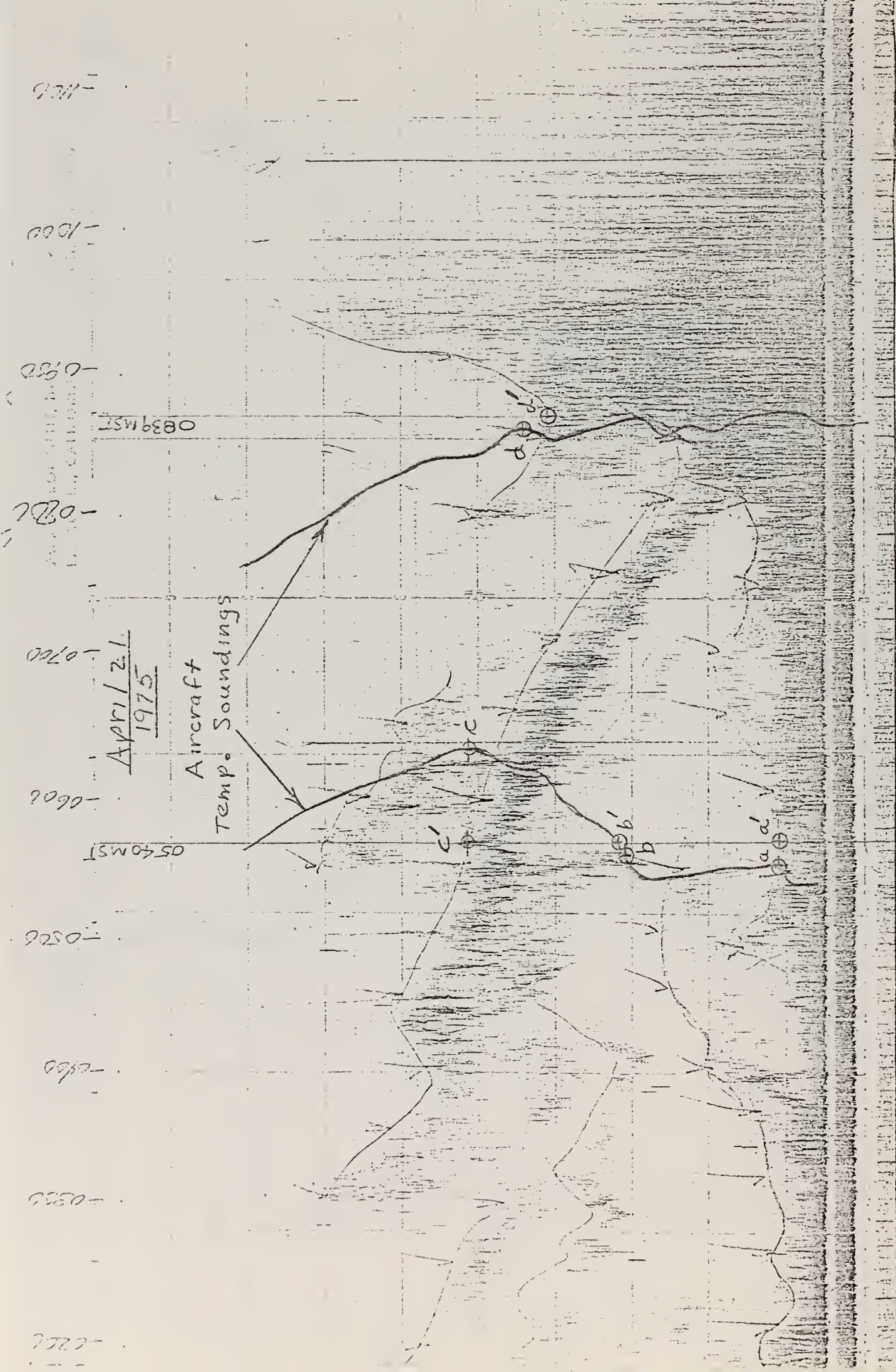


Figure 4.1-3 Composite of Figures 4.1-1 and 4.1-2

ACOUSTIC SOUNDER PATTERN CLASSIFICATION (Table 1 of Reference 13)

Code	Characteristics
0	Missing, indefinable or random noise — these records usually occur under strong wind or rain type conditions when the ambient noise levels saturate the incoming acoustic signals. They are characterised by a uniform grey, a white (= saturation of the pre-amplifier) or a homogeneous grey mottled type of record.
1	Bottom layer only, homogeneous and/or 'spiky', thin ~ 150 m thick — a uniform intensity pattern with vertical spikes not exceeding 150 — 300 m, but sometimes varying in height with time. Usually associated with only a slight mottling of the chart above the surface layer.
2	Bottom layer only, homogeneous and/or 'spiky', thick > 300 m — similar comments apply as for pattern type 1. The uniform vertical 'spikes' or 'grass' type of records show no horizontal layering and are usually associated with low ambient noise and wind turbulence levels.
3	Bottom layer only, wavy and/or complex, thin ~ 300 m — the patterns can form horizontal layers (wavy) or intensity variations (complex) which vary both in height with time and also echo intensity.
4	Bottom layer only, wavy and/or complex, thick ~ 450 m — usually more intense near the ground, these patterns show temporal height variability in the horizontal layers. The complex layers may also have higher frequency waves or spikes with intermittent echo free zones.
5	Double layer, separation indistinct or small — when viewed over several hours of record there is generally a clear zone less than 150 m thick separating two distinct layers of stronger echoes. This zone is not always echo free but can have a mottled effect or noise superimposed. The continuity of the clear zone contrasts with the intermittent appearance of similar zones in pattern types 3 and 4. The layers are usually horizontal, neither ascending nor descending with time.
6	Double layer, separation distinct or large — these records are observed under a variety of conditions; during either day or night; with high or low ambient noise levels. The upper layer is usually thinner (~ 150 m thick) than the lower layer and clearly separated by 300 to 600 m generally echo free zones. Again the layers are horizontal and neither descend nor ascend with time.
7	Multiple or complex layers, weak intensity — these echo patterns may appear at any altitude and usually have more than two horizontal wave type layers with indistinct separations. Frequently intermittent or fragmented layers or patches are observed in the case of the complex patterns. In general there is no overall ascent or descent with time, but individual layers may show considerable height variability on a shorter time scale. The mottled grey record synonymous with the higher ambient noise levels is usually superimposed on these patterns.

(continued)

Table 4.1-1 (continued)

Code	Characteristics
8	Multiple or complex layers, strong intensity -- the intense multiple layers are typified by distinct echo free zones usually varying in thickness with time. In the case of the complex echo patterns higher ambient noise levels are usually observed with high frequency waves (period of 5 to 10 minutes) and large amplitudes (~ 300 m). Again there may be intermittent or fragmented layers or patches of echoes in this pattern group.
9	Ascending echo, emerging or incipient -- this echo pattern has its origins in a layer close to the ground and emerges to give an ascending echo with clear separation from the surface layer. Several hours of record need to be viewed in order to extrapolate back in time to the incipient echoes which usually only last for a period of about one hour.
10	Ascending echo, advanced -- this echo pattern may not only have its origin in the type 9 pattern but it may also be present as a separate entity higher in the atmosphere. The rate of rise of these layers is about 225 m h^{-1} . In general the mottled effect or higher ambient noise levels are superimposed.
11	Descending echo, clear or large separation -- again this pattern must be interpreted over several hours. The layer thickness may vary in time with an intermittent intensity. There is usually a stronger surface echo of type 1 or 2 associated with the descending layer under nocturnal conditions. During the daytime, type 13 echoes are typically observed being generated from the surface layer below the elevated echo. <u>Note:</u> In classifying the cascading or multiple descending layers, the individual layers should be traced until merging with the surface layer (becomes type 12) and then reclassified as type 11 for the succeeding pattern (see example in Figure 5).
12	Descending echo, merging with the bottom layer -- the merging of the descending echo with the surface layer may take several hours, but occasionally it has been observed to occur much more quickly. A thickening of the surface echo pattern usually results. The transition from pattern type 11 to 12 occurs when the separation between the descending and surface layers becomes indistinct and/or < 150 m.
13	Thermal plume type structure with well defined 'spikes' or 'grass' in the echo patterns-- these patterns are typified by broad based intense echoes usually tapering with height to leave echo free zones reaching nearly to the ground. Having thermal origins, these patterns usually occur during the daytime, however, this is not an exclusive condition. If observed at nighttime, the wind and consequently the ambient noise levels are much lower than during the day.

have been performed. The analyses compare acoustic-sounder measurements of altitude of temperature inversions with aircraft measurement of temperature versus altitude and determination of altitude of inversions. The first comparison was of published data for both the sounder and aircraft at the C-b meteorological tower site. A second analysis was then performed on a reinterpretation of these data. A third analysis is based on pooling the published data with reinterpreted data and searching for best agreement. A final statistical analysis was performed on the trends indicated.

4.2.1 The Data:

The C-b Project Quarterly Reports of environmental data, references 15 to 18, are the primary sources of data. Additional, acoustic-sounder data are contained in reference 11. Additional, aircraft data are contained in reference 10. Since the aircraft flights were on specific days at specific times, the corresponding acoustic-sounder data were extracted from continuous records for these times. These data are tabulated by day in Appendix A along with plots of the aircraft altitude versus temperature. Columns 1 and 3 of the table insert on the Appendix A figures represent EG&G interpretation of aircraft data and Marlatt and Associates' interpretation of acoustic-sounder data. Columns 2 and 4 are reinterpretations of the data by the authors.

For this study, all reported inversions below the ground level of the C-b meteorological tower site (approximate elevation 7000 feet) were disregarded. These were obtained as the aircraft flew up the canyon from Piceance Creek to the tower site and elevation. Also, aircraft-reported inversions above 3000 feet were disregarded since acoustic sounder upper range at this site is about 3000 feet above the surface. Disregarded data are circled in the table inserts in Appendix A. All elevations are reported in feet above the base of the tower. Comparisons are made for each flight where both aircraft data and acoustic-sounder data are available.

The basis of comparison is the proportion of agreement between aircraft and acoustic-sounder, inversion, altitude determinations. To obtain the proportion of agreement, the data were grouped into five classes as follows:

- Class 1 - Agree that no temperature inversion is indicated. Neither EG&G nor Marlatt and Associates reported inversion.
- Class 2 - Agree that inversion exists and reported heights agree within 250 feet.
- Class 3 - Disagree in that both report inversions but height differences are greater than 250 feet.
- Class 4 - Disagree in that Marlatt and Associates report inversion and EG&G do not.

Class 5 - Disagree in that EG&G report inversion and
Marlatt and Associates do not.

4.2.2 Previously Published Data:

EG&G Environmental Consultants collected and interpreted the aircraft data. Marlatt and Associates collected and interpreted the acoustic-sounder data. These data have been published in references 10, 11, 15-18. This analysis is based on these data as tabulated in Appendix A.

The data were tabulated into these classes for the three seasonal periods where concurrent data were available. Table 4.2-1 shows the tabulation. Also shown is the total of all data by class and the percent of total observations in each class. The predominant class is Class 1 where neither aircraft nor acoustic sounder identified an inversion.

Table 4.2-2 presents the statistics of the analysis for each season and total. The hypotheses being tested are that there is agreement of 95 percent and 90 percent, respectively, at the 5 percent level of significance. The level of significance is the probability of rejecting a true hypothesis. Testing hypotheses of 95 percent and 90 percent agreement are based on the probability that there is in fact better agreement in the data than interpretations are detecting. Statistical variations in the consistency of interpretations as well as probable errors resulting from selecting coincidental times, aircraft sounding not being directly over the sounder, and recording errors would tend to decrease the agreement in the independently interpreted data. Testing hypotheses of higher levels of agreement than the best estimates provide for data-bias offset within the limits of sample variability.

Best estimate of agreement is 74.2 percent. Based on the combined total data, one must reject the hypothesis of 90 percent agreement at the 5 percent level of significance. However, this conclusion is immediately suspect since the winter quarter data appear to be significantly lower than the spring and summer data. If this is true, one may conclude that there is a significant trend toward better agreement with the latter data. It would also provide a statistical basis for combining only spring and summer data as a separate sample.

To determine if there is a statistically significant difference between the winter data and the spring data, one may test the null hypothesis that the sample proportions are equal. This test follows:

Hypothesis: $p_{\text{(winter)}} = p_{\text{(spring)}}$

$\alpha = .05 = \text{level of significance}$

Reject H if $t > t_{1-\alpha} \quad (87 \text{ df})$

$t > 1.66$

Table 4.2-1

COMPARISON OF PUBLISHED AIRCRAFT
AND ACOUSTIC SOUNDER INVERSION DATA

CLASS	JAN. FEB. 1975	APRIL MAY 1975	JULY 1975	TOTAL	TOTAL PERCENT
1. Agree No Inversion	24	30	26	80	64.5
2. Agree Inversion $\pm$ 250 ft.	6	2	4	12	9.7
3. Disagree On Inversion Height	5	1	0	6	4.8
4. Disagree on Inversion Marlatt Records	12	6	1	19	15.3
5. Disagree on Inversion EG&G Records	3	0	4	7	5.6
Total Comparisons	50	39	35	124	99.9

Table 4.2-2

STATISTICAL ANALYSIS OF PUBLISHED DATA

	Winter	Spring	Summer	Total	Spring Summer
Sample Size = N	50	39	35	124	74
Sample Proportion of Agreement = p	.600	.821	.857	.742	.858
Standard Deviation $S = \sqrt{p(1-p)/N}$	.0693	.0615	.0591	.0393	.0428
Test Hypothesis: $p_0 = 0.95$ p_0 = True Proportion: $\alpha = 0.05$	Reject	Reject	Accept	Reject	Reject
Test Hypothesis: $p_0 = 0.90$ p_0 = True Proportion: $\alpha = 0.05$	Reject	Accept	Accept	Reject	Accept

Calculate t

$$t = \frac{P(\text{spring}) - P(\text{winter})}{\sqrt{(S_{\text{spring}})^2 + (S_{\text{winter}})^2}}$$
$$t = \frac{.821 - .600}{\sqrt{(.0615)^2 + (.0693)^2}} = 2.39$$

Reject H and accept alternative that a significant difference in mean proportions does exist.

Similar tests would also show that the winter data are significantly lower than summer data and that no difference exists between spring and summer data. This provides a statistical basis for treating spring and summer data as a combined sample and again testing the hypotheses of 95 percent and 90 percent proportion of agreement respectively between the aircraft and acoustic-sounder published data on heights of inversions. Results of these tests are also shown in Table 4.2-2 in the last column. This shows that the best estimate of agreement is 83.8 percent and that the hypothesis of 90 percent is accepted.

Inferences that may be drawn from analysis of the published data are as follows:

- a. There is a significant trend toward better data agreement in the published data from winter to spring and summer.
- b. The best estimate of agreement between the published data for spring and summer is 83.8 percent.
- c. The probable effect of errors in data interpretation is to reduce the percent of agreement.
- d. Based on a combined sample of spring and summer data, one would accept the hypothesis of 90 percent agreement between the published data at the 5 percent level of significance. By the same test one would reject the hypothesis of 95 percent agreement.

The trend that is indicated across the seasons may be due to several factors. Table 4.2-1 shows a higher frequency of observations in all classes except Class 1, no inversion, for the winter data. This indicates more complex signatures on the acoustic sounder data with greater frequency of indicated temperature inversions. These complex signatures are difficult to interpret. This, coupled with probable learning as experience is gained in interpretation and a possible change in criteria for identification are partial explanations for the differences.

4.2.3 C-b Reinterpreted Data:

The writer, while claiming no expertise whatever in interpretation of either aircraft or acoustic sounder data, undertook a reinterpretation of both sets of data. The reinterpretations were carried out under conditions that attempted to be independent of the published data and of each type of data. This was not completely possible since the acoustic-sounder data had pencil marks from previous interpretations. The reinterpreted data are shown in the tabulations in Appendix A as C-b Reinterpretations. This analysis is based on those data.

Table 4.2-3 shows C-b Reinterpretation tabulated into the previously identified classes. These data were reduced and analyzed in the same manner as the published data. The results of the analyses are shown in Table 4.2-4. The results of this analysis are initially surprising since relaxed criteria for identifying inversions were thought to be applied to both the aircraft and acoustic sounder data. The relaxed criteria were 1) $+1 C^0$ in 300 feet increase in slope for aircraft data to indicate an inversion; 2) less pronounced echo lines for acoustic-sounder inversion identification; and 3) a ± 300 -foot versus 250-foot inversion-height spread for agreement comparisons. However, there is even less agreement shown by the reinterpretation of the data. Again, the winter data are significantly lower in agreement than the spring and summer samples and this cannot be attributed to learning. It underscores the difficulty in interpreting acoustic-sounder data for winter conditions. The best estimate of agreement is 69.8 percent based on spring and summer data. Under no conditions can an hypothesis of 90 percent agreement at the 5 percent level of significance be accepted.

Comparing Table 4.2-3 with Table 4.2-1, the principal differences are a decrease in the "no inversions class" and an increase in all other classes in the C-b reinterpreted data. This is a direct result of the relaxed criteria for interpretation of both aircraft and acoustic-sounder data. It is also the principal reason for reducing the percentage of agreement between the C-b reinterpreted data and the published data since a greater percent of change occurred in Classes 4 and 5 than in Class 2. Increasing from 250 feet to 300 feet for agreement on inversion altitude was not a factor. The tendency to report inversions from the acoustic-sounder data was increased from 37 to 67 by the C-b reinterpretation. Inversions reported for aircraft data were increased from 25 to 47 by the C-b reinterpretations.

One further comparison is of interest. If Class 1 is disregarded and comparison is based only on the cases where either the aircraft or acoustic data or both indicate inversions, the agreement is nearly the same as indicated by the ratio of Class 2 to the total of Classes 2 through 5. These ratios are:

Published data	12/44	=	27.3%
C-b Reinterpreted	26/81	=	32.1%

Table 4.2-3

COMPARISON OF C-b REINTERPRETATION
OF ACOUSTIC SOUNDER AND AIRCRAFT DATA

CLASS	JAN. FEB. 1975	APRIL MAY 1975	JULY 1975	TOTAL	TOTAL PERCENT
1. Agree No Inversion	14	24	19	57	41.3
2. Agree Inversion $\pm$ 300 ft.	9	9	8	26	18.8
3. Disagree On Inversion Height	5	0	2	7	5.1
4. Disagree on Inversion Acoustic Sounder Records	19	13	2	34	24.6
5. Disagree on Inversion Aircraft Records	5	1	8	14	10.1
Total Comparisons	52	47	39	138	99.9

Table 4.2-4

STATISTICAL ANALYSIS OF
C-b REINTERPRETED DATA

	Winter	Spring	Summer	Total	Spring Summer
Sample Size = N	52	47	39	138	86
Sample Proportion of Agreement = p	.442	.702	.692	.601	.698
Standard Deviation $S = \sqrt{p(1-p)/N}$	.0689	.0667	.0615	.0417	.0495
Test Hypothesis: $p_0 = 0.95$ p_0 = True Proportion: $\alpha = 0.05$					
Test Hypothesis: $p_0 = 0.90$ p_0 = True Proportion: $\alpha = 0.05$	Reject	Reject	Reject	Reject	Reject

These ratios indicate the degree of agreement on height of inversion, given that an inversion is indicated in either set of data.

4.2.4 Comparisons of Interpretations of Temperature Inversion Data:

This section analyzes the agreement between C-b reinterpretation and the published data for both aircraft and acoustic sounder.

4.2.4.1 Aircraft Data:

A comparison of the agreement between EC&G published data and the C-b reinterpretation of these data using relaxed criteria has been performed. The results of this analysis are shown in Table 4.2-5. The data being compared are shown in Appendix A. Where more than one entry occurs for a given flight, all data are used and tabulated in the appropriate classes in Table 4.2-5. This results in totals that vary slightly from tabulations in previous tables.

Table 4.2-5 shows the percent of agreement to be 74.6 with 23.0 percent of the tabulations in Class 5. The relaxed criteria have included changes in slope of the temperature versus altitude plots which were suspected to be indicated as inversions in the acoustic sounder data. There were 23 percent more inversions identified in the C-b reinterpreted data than in the EC&G published data.

4.2.4.2 Acoustic-Sounder Data:

C-b reinterpretation of acoustic sounder data were compared with Marlatt and Associates previously published data in a manner identical to that reported in the previous section. The results of this analysis are shown in Table 4.2-6. Again the data being compared are shown in Appendix A.

Table 4.2-6 shows the percent of agreement to be 75.6 percent with 23.7 percent of the tabulations in Class 5. It is coincidental that these numbers are so close to the percentages for aircraft data. The readings were totally independent of each other. Again, the relaxed criteria for identifying a suspected inversion accounts for the percentages. There are 23.7 percent more inversions identified in the C-b reinterpreted data than in the Marlatt and Associates published data.

4.2.5 Best Agreement from All Data:

A final statistical analysis was based on searching for best agreement between aircraft and acoustic sounder data. For this analysis both the previously published data and the C-b reinterpreted data were pooled and searched for the best agreement between aircraft and acoustic-sounder, temperature, inversion data. For example, see Figure A-1 in Appendix A, where the flight at 17:51 was originally a disagreement between the published data and now tabulated as agreement in the pooled data. The results of this analysis are shown in Table 4.2-7.

Table 4.2-5

COMPARISON OF C-b REINTERPRETATION
WITH EG&G PUBLISHED AIRCRAFT
TEMPERATURE INVERSION DATA

CLASS	JAN. FEB. 1975	APRIL MAY 1975	JULY 1975	TOTAL	TOTAL PERCENT
1. Agree No Inversion	24	30	20	74	58.7
2. Agree Inversion $\pm$ 300 ft.	12	2	6	20	15.9
3. Disagree On Inversion Height	0	1	2	3	2.4
4. Disagree on Inversion EG&G Records	0	0	0	0	0.0
5. Disagree on Inversion C-b Reinterpretation Records	12	7	10	29	23.0
Total Comparisons	48	40	36	126	100.0

	Winter	Spring	Summer	Total	
Sample Size = N	48	40	38	126	
Sample Proportion of Agreement = p	.750	.800	.684	.746	
Standard Deviation $S = \sqrt{p(1-p)/N}$	.0625	.0623	.0754	.0388	

Table 4.2-6

COMPARISON OF C-b REINTERPRETATION
WITH MARLATT PUBLISHED ACOUSTIC
SOUNDER TEMPERATURE INVERSION DATA

CLASS	JAN. FEB. 1975	APRIL MAY 1975	JULY 1975	TOTAL	TOTAL PERCENT
1. Agree No Inversion	9	24	26	59	45.0
2. Agree Inversion $\pm$ 300 ft.	23	11	6	40	30.5
3. Disagree On Inversion Height	0	0	0	0	0.0
4. Disagree on Inversion Marlatt Records	0	1	0	1	0.8
5. Disagree on Inversion C-b Reinterpretation Records	14	11	6	31	23.7
Total Comparisons	46	47	38	131	100.0

	Winter	Spring	Summer	Total	
Sample Size = N	46	47	38	131	
Sample Proportion of Agreement = p	.696	.745	.842	.756	
Standard Deviation $S = \sqrt{p(1-p)/N}$	.0678	.0636	.0592	.0497	

Table 4.2-7

COMPARISON OF AIRCRAFT AND ACOUSTIC
SOUNDER TEMPERATURE INVERSION DATA
BASED ON BEST AGREEMENT FROM ALL DATA

CLASS	JAN. FEB. 1975	APRIL MAY 1975	JULY 1975	TOTAL	TOTAL PERCENT
1. Agree No Inversion	24	30	27	81	60.9
2. Agree Inversion $\pm$ 300 ft.	15	14	9	38	28.6
3. Disagree On Inversion Height	4	0	1	5	3.8
4. Disagree on Inversion Acoustic Sounder Records	7	1	0	8	6.0
5. Disagree on Inversion Aircraft Records	0	0	1	1	0.7
Total Comparisons	50	45	38	133	100.0

	Winter	Spring	Summer	Total	Spring Summer
Sample Size = N	50	45	38	133	83
Sample Proportion of Agreement = p	.780	.978	.947	.895	.964
Standard Deviation $S = \sqrt{p(1-p)/N}$	.0586	.0220	.0362	.0266	.0205
Test Hypothesis: $P_0 = 0.95$ $P_0 = \text{True Proportion: } \alpha = 0.05$	Reject	Accept	Accept	Accept	Accept
Test Hypothesis: $P_0 = 0.90$ $P_0 = \text{True Proportion: } \alpha = 0.05$	Accept				Reject

α = Level of significance = probability of rejecting true hypothesis.

This analysis is based on two independent attempts to interpret the same data but in one case with relaxed criteria for identification of temperature inversions. For a tabulation to appear in one of the disagreement classes, Class 3, 4, or 5, means that both interpretations of acoustic sounder data disagree with both interpretations of aircraft data. In the case of agreement, in all but 5 of the 119 tabulations the agreement was between three out of four sets of paired observations. The other five contained agreement in one out of four possible pairings of the data.

Table 4.2-7 shows 89.5 percent agreement between aircraft and acoustic sounder data under the conditions explained above. One would accept the hypothesis of 95 percent agreement. Again the winter data are found to be significantly lower than the spring and summer data. Combining the spring and summer data only shows 96.4 percent agreement in these data and this is significantly higher than the hypothesis of 90 percent agreement.

If one looks only at Classes 2 through 5 where inversions are indicated in some or all of the data, the ratios of agreement on height of inversions are:

All of data	=	38/52 = 73.5 percent
Spring and summer data	=	23/26 = 88.5 percent
Winter data	=	15/26 = 57.7 percent

These ratios are considerably higher than the one out of three shown in paragraph 4.2.3 indicating the potential for improving interpretation of acoustic-sounder data.

4.3 Trends:

The preceding analyses have shown that there is a significant increase in the agreement between acoustic sounder and aircraft temperature inversion data for spring and summer data over the winter data. As explained previously, this is partially due to the greater frequency of inversions during the winter aircraft flights and the more complex acoustic sounder signatures at this time. Learning may be a factor in improved interpretation in the later seasons but the C-b reinterpretation of both sets of data would not indicate this to be a significant factor. Other factors affecting the quality of the acoustic-sounder data may be present such as snow in the antenna dish, cold temperature effect on the electromechanical apparatus.

5. CONCLUSIONS

1. The best estimate of agreement between the acoustic-sounder and aircraft published data on the frequency of inversions is 84%. One would not reject the hypothesis of 90% agreement at the 5% level of significance.

2. The best estimate of agreement between the acoustic-sounder and aircraft reinterpreted data is 70%. One would reject the hypothesis of 90% agreement at the 5% level of significance.

3. Relaxing the criteria for both aircraft and acoustic-sounder inversion identification nearly doubled the inversion count for both.

4. For classes 2 through 5 (for which one or both indicated an inversion), the agreement on inversion height to within ± 300 feet is 1 in 3 for both published and reinterpreted data.

5. By pooling the published and reinterpreted data and searching for best agreement, the best estimate of agreement between the acoustic-sounder and aircraft is 96%. One would accept the hypothesis of 95% agreement at the 5% level of significance.

6. For classes 2 through 5, the agreement on inversion height to within ± 300 feet is 3 out of 4 for the pooled data.

7. For the published data, the reinterpreted data, and the pooled data the winter data are significantly lower in proportion of agreement than either spring or summer data.

8. The aircraft and the acoustic-sounder are a valuable adjunct to each other; the former is invaluable in interpreting the latter. Continuous inversion-monitoring is provided by the sounder at relatively low cost. This study has lent sufficient confidence to continued use of the acoustic-sounder at the C-b Tract.

6. RECOMMENDATIONS

1. Techniques to improve both classification and interpretation of sounder records are needed.

2. An extension of this study to correlate records of both sounders with each other should assist in consistent interpretation of sounder records.

7. REFERENCES

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15. Tract C-b Quarterly Report #2, U. S. Department of the Interior Prototype Oil Shale Leasing Program, Prepared by the C-b Shale Oil Project, 1700 Broadway, Denver, Colorado 80202. April 14, 1975. 13 Volumes.
16. Tract C-b Quarterly Report #3, U. S. Department of the Interior Prototype Oil Shale Leasing Program, Prepared by the C-b Shale Oil Project, 1700 Broadway, Denver, Colorado 80202. July 15, 1975. 17 Volumes.
17. Tract C-b Quarterly Report #4, U. S. Department of the Interior Prototype Oil Shale Leasing Program, Prepared by the C-b Shale Oil Project, 1700 Broadway, Denver, Colorado 80202. October 15, 1975. 4 Volumes.
18. Tract C-b Quarterly Report #5, U. S. Department of the Interior Prototype Oil Shale Leasing Program, Prepared by the C-b Shale Oil Project, 1700 Broadway, Denver, Colorado 80202. January 15, 1976. 5 Volumes.

APPENDIX A

Summary of Aircraft Temperature-Versus-
Altitude Data and Inversion Altitude
Interpretations from Acoustic Sounder Data.

Contains 37 Charts

This appendix contains thirty-seven charts of aircraft measurements of upper air temperature versus altitude. These data were collected and compiled by EG&G, Environmental Consultants. Tabulated on each chart are interpretations of temperature inversion altitudes for the aircraft data and for acoustic sounder data collected and compiled by Marlatt Associates. The tabulation also shows a reinterpretation of both the aircraft data and the acoustic sounder data. The reinterpretations are identified as C-b REINTERP.

The tabulated data are used in the statistical analyses of Section 4 of this report.

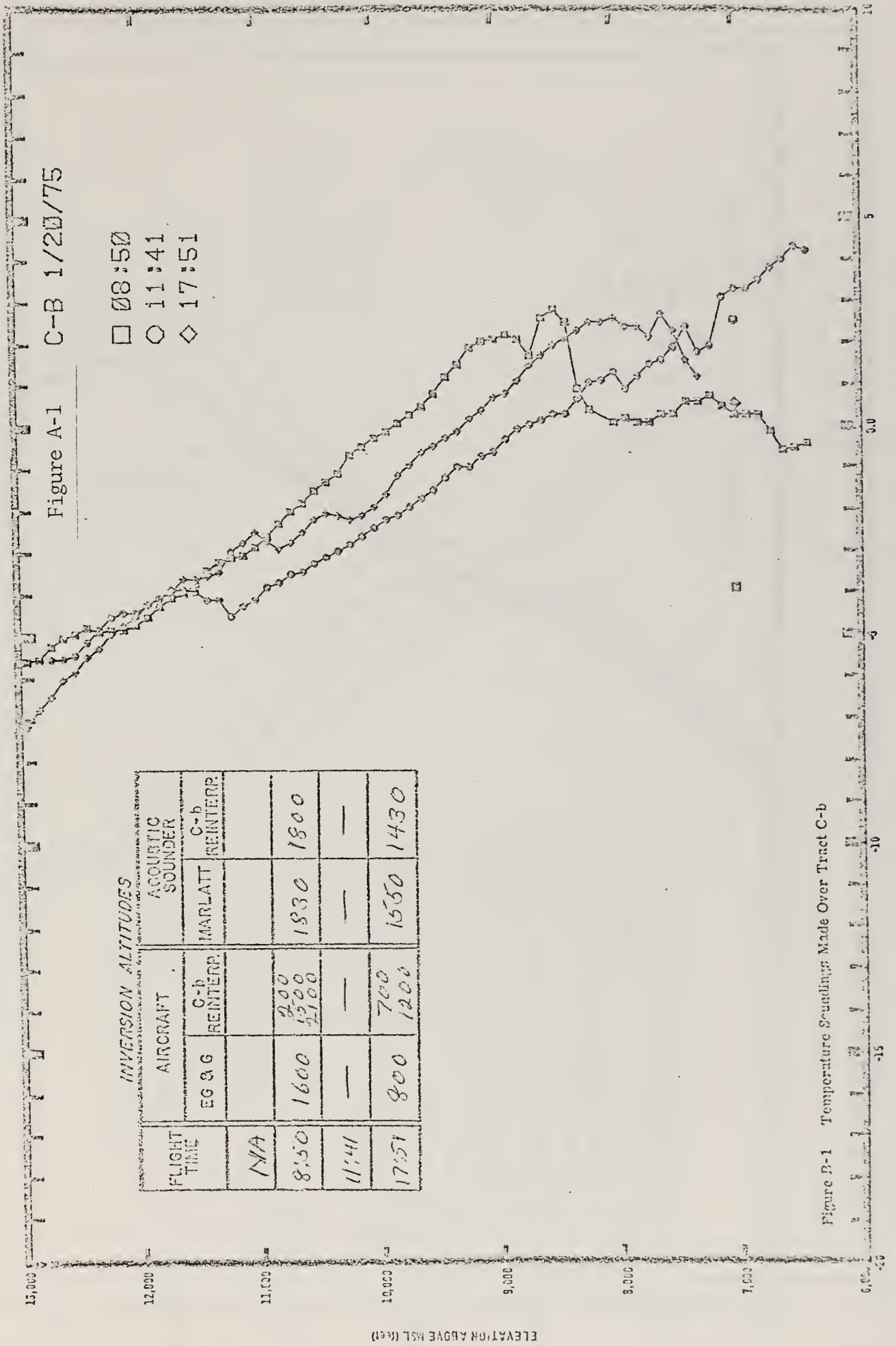


Figure A-1 C-B 1/20/75

□ 08:50
 ○ 11:41
 ◇ 17:51

FLIGHT TIME	AIRCRAFT		ACQUSTIC SOUNDER	
	EG 3 G	C-b REINTERP	MARLATT	C-b REINTERP
N/A				
8:50	1600	200 1500 2100	1830	1800
11:41	—	—	—	—
17:51	800	700 1200	1550	1430

Figure B-1 Temperature Soundings Made Over Tract C-b

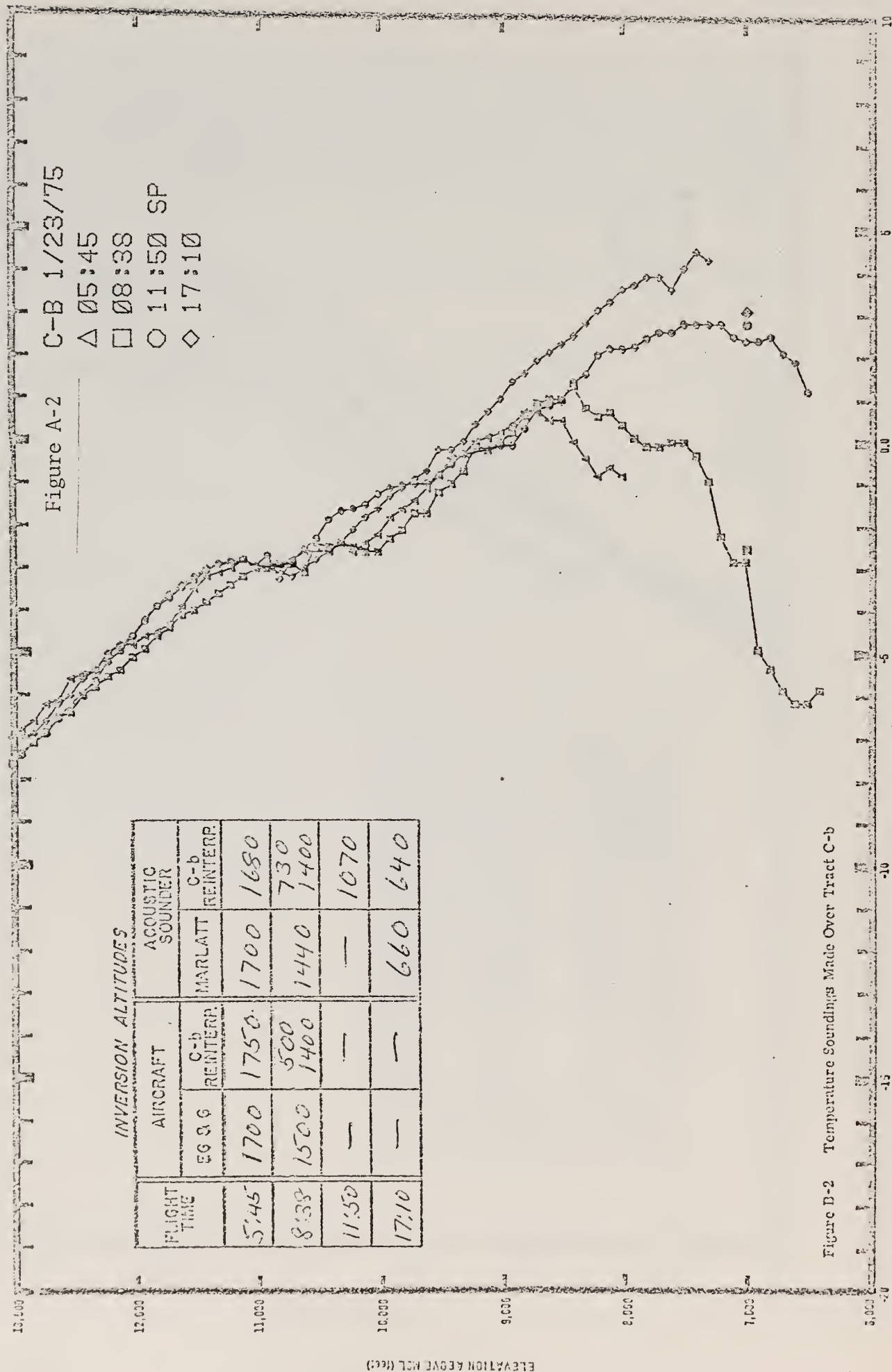
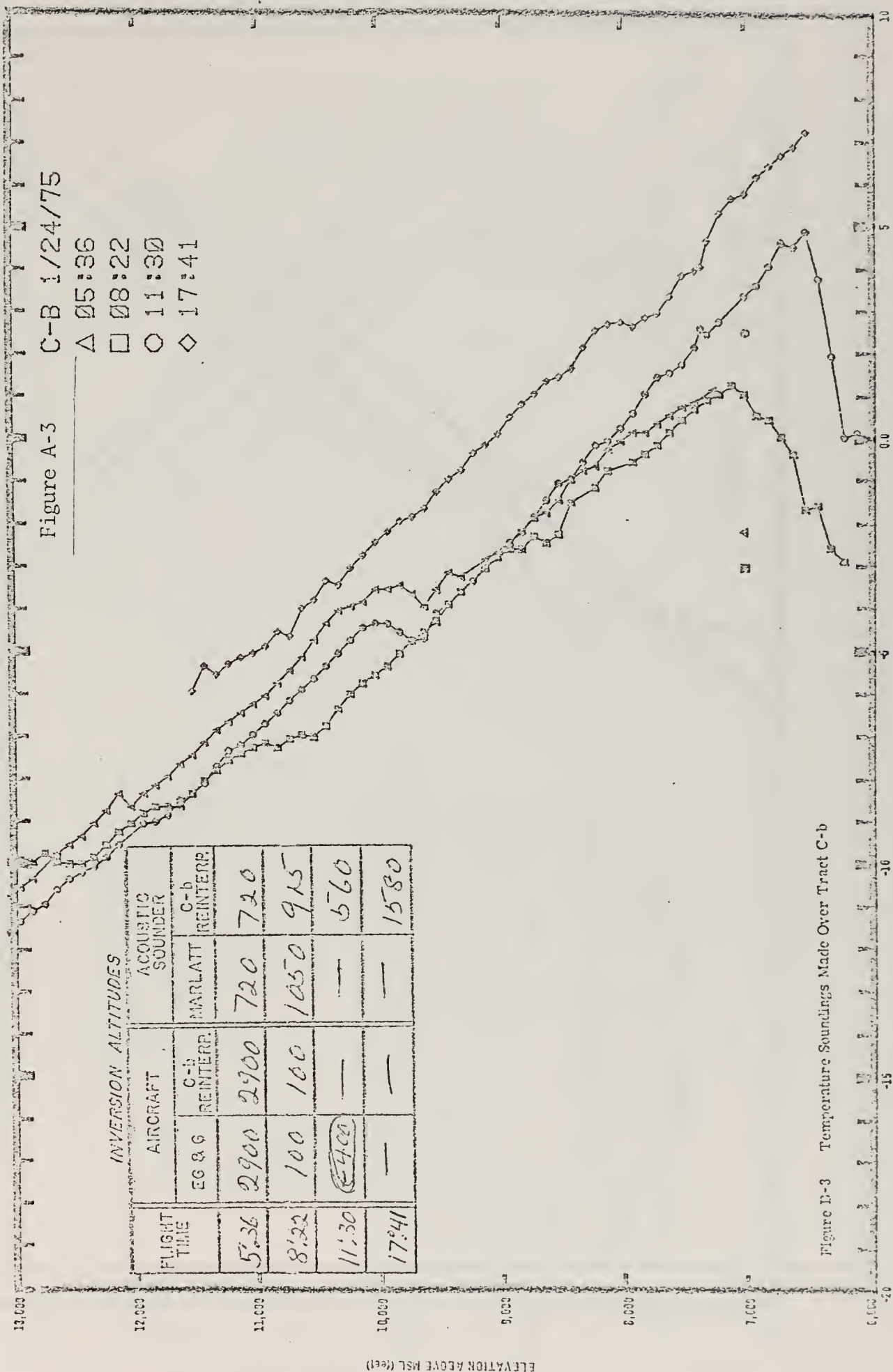


Figure B-2 Temperature Soundings Made Over Tract C-b



ELEVATION ABOVE MSL (feet)

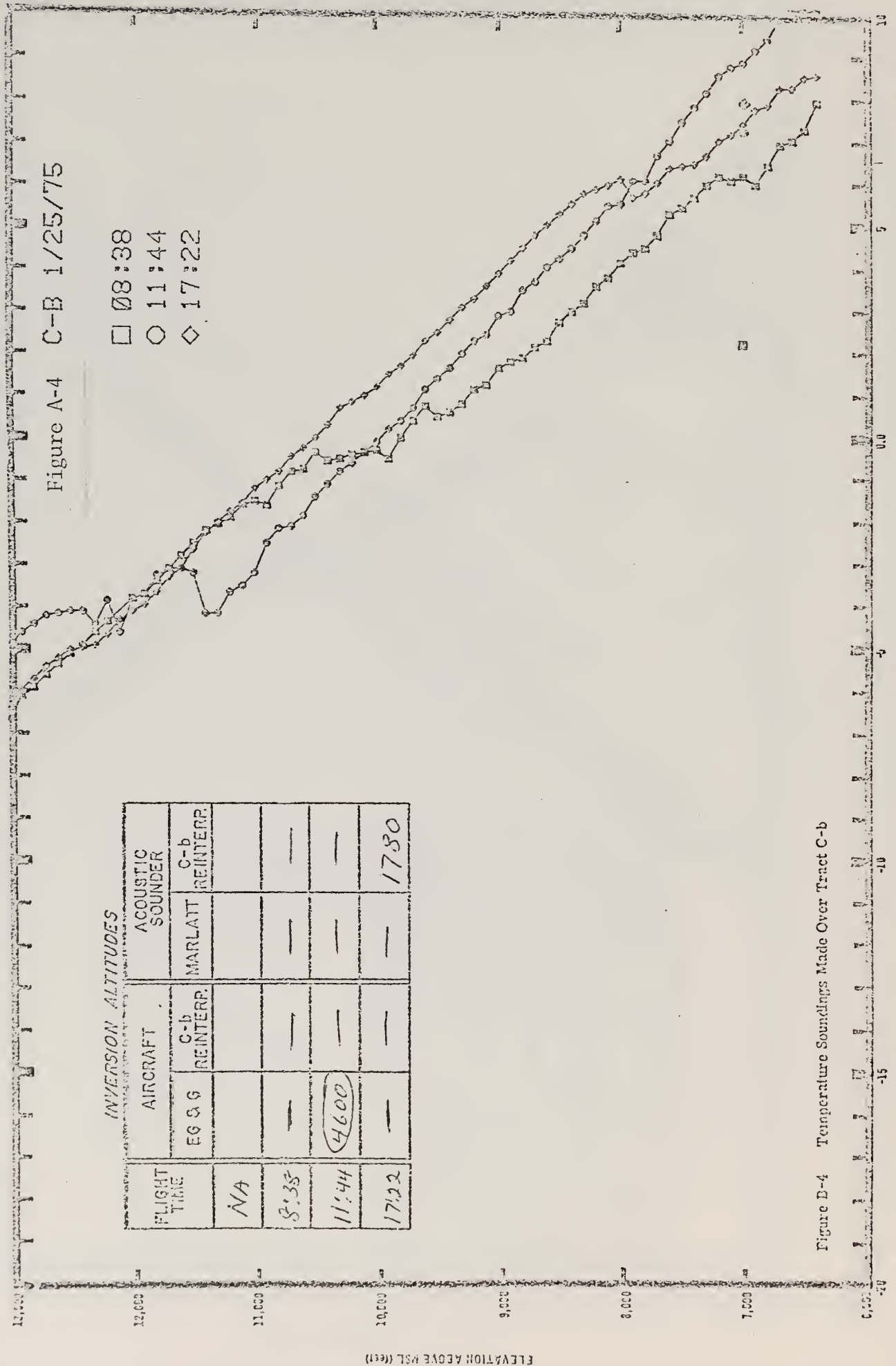


Figure D-4 Temperature Soundings Made Over Tract C-b

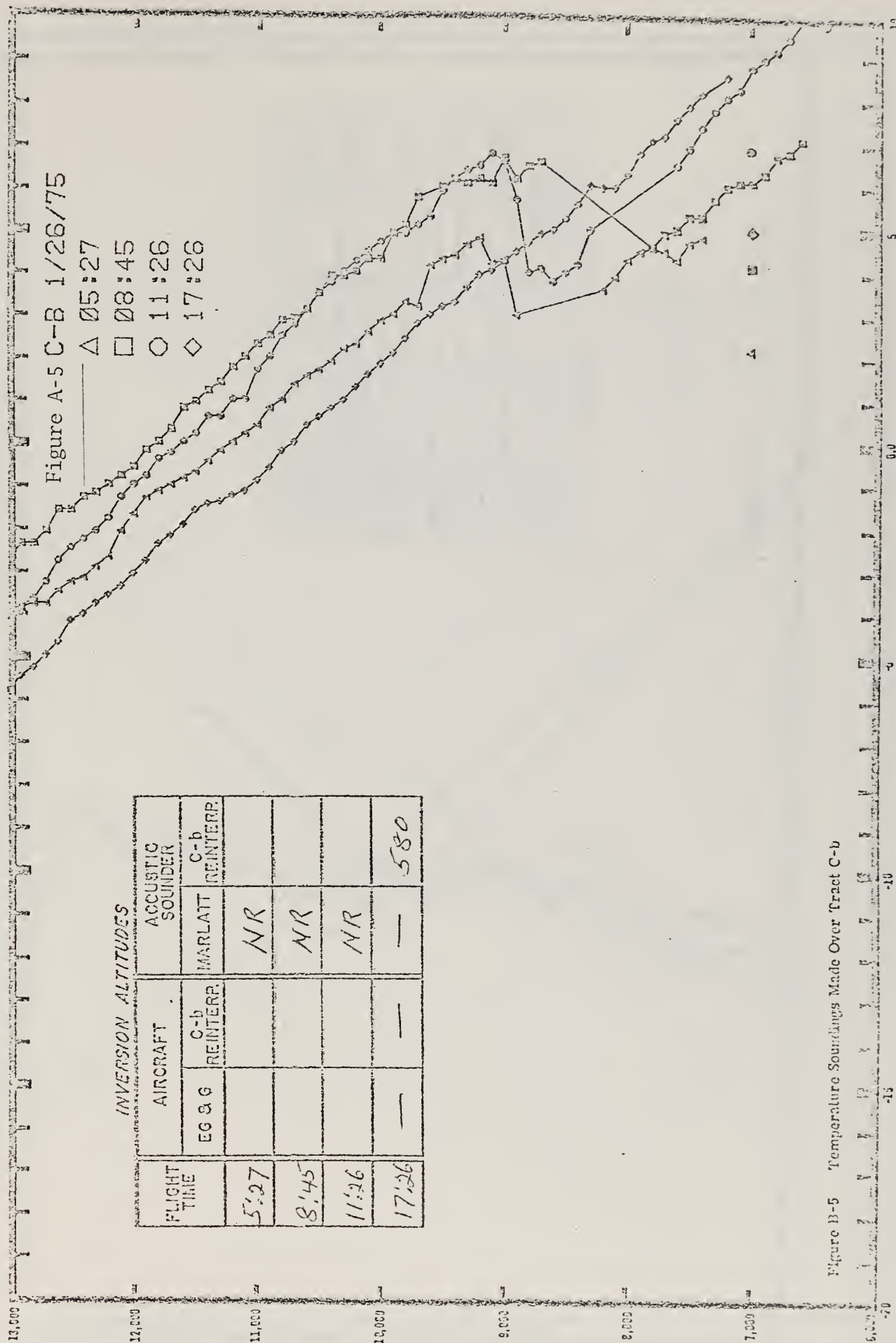


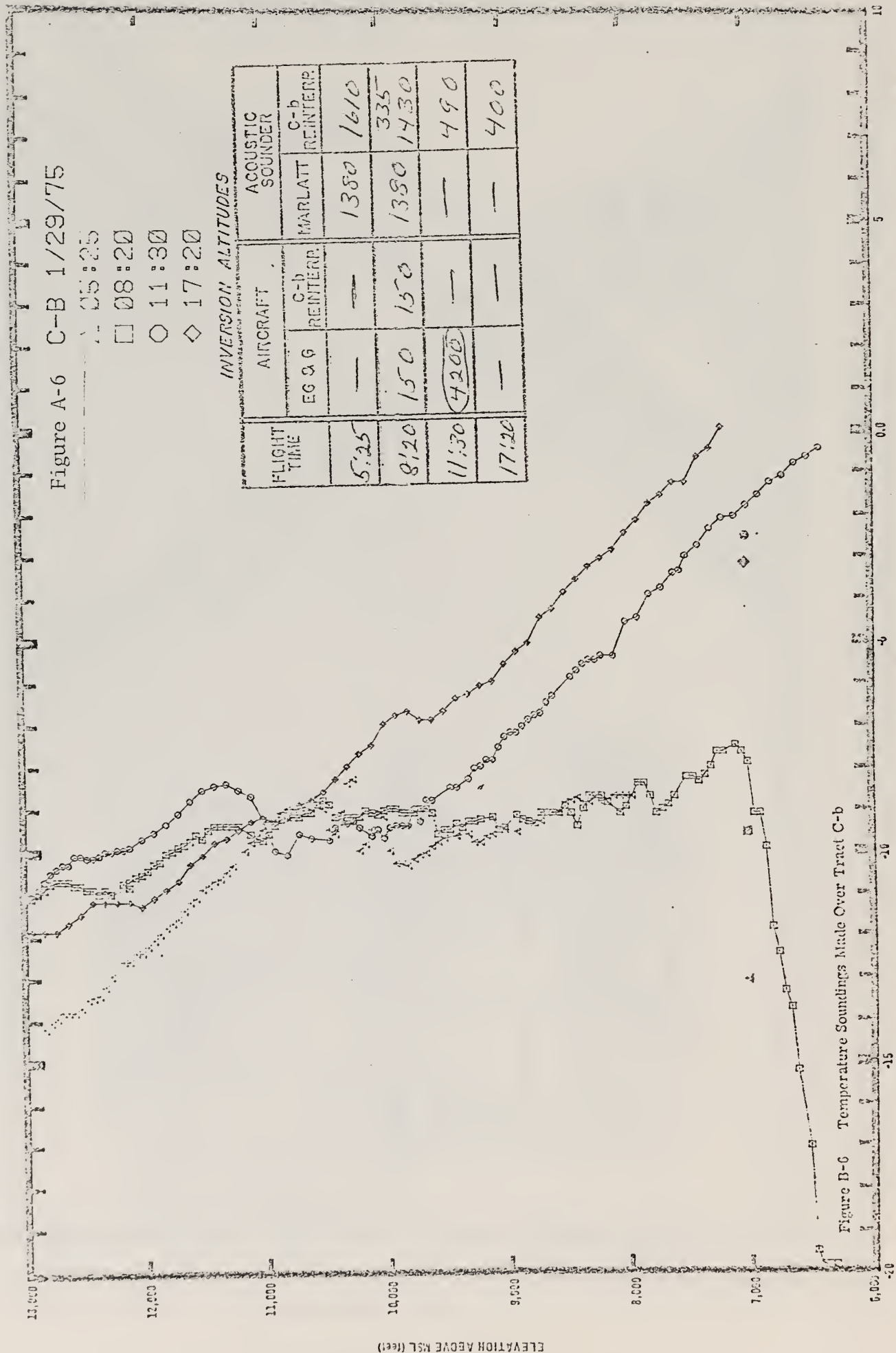
Figure A-5 C-B 1/26/75

△ 05:27
 □ 08:45
 ○ 11:26
 ◇ 17:26

FLIGHT TIME	INVERSION ALTITUDES		ACQUSTIC SOUNDER	
	EG & G	C-b REINTERR.	MARLATT	C-b REINTERR.
5:27			NR	
8:45			NR	
11:26			NR	
17:26	—	—	—	580

Figure B-5 Temperature Soundings Made Over Tract C-b

ELEVATION ABOVE MSL (feet)



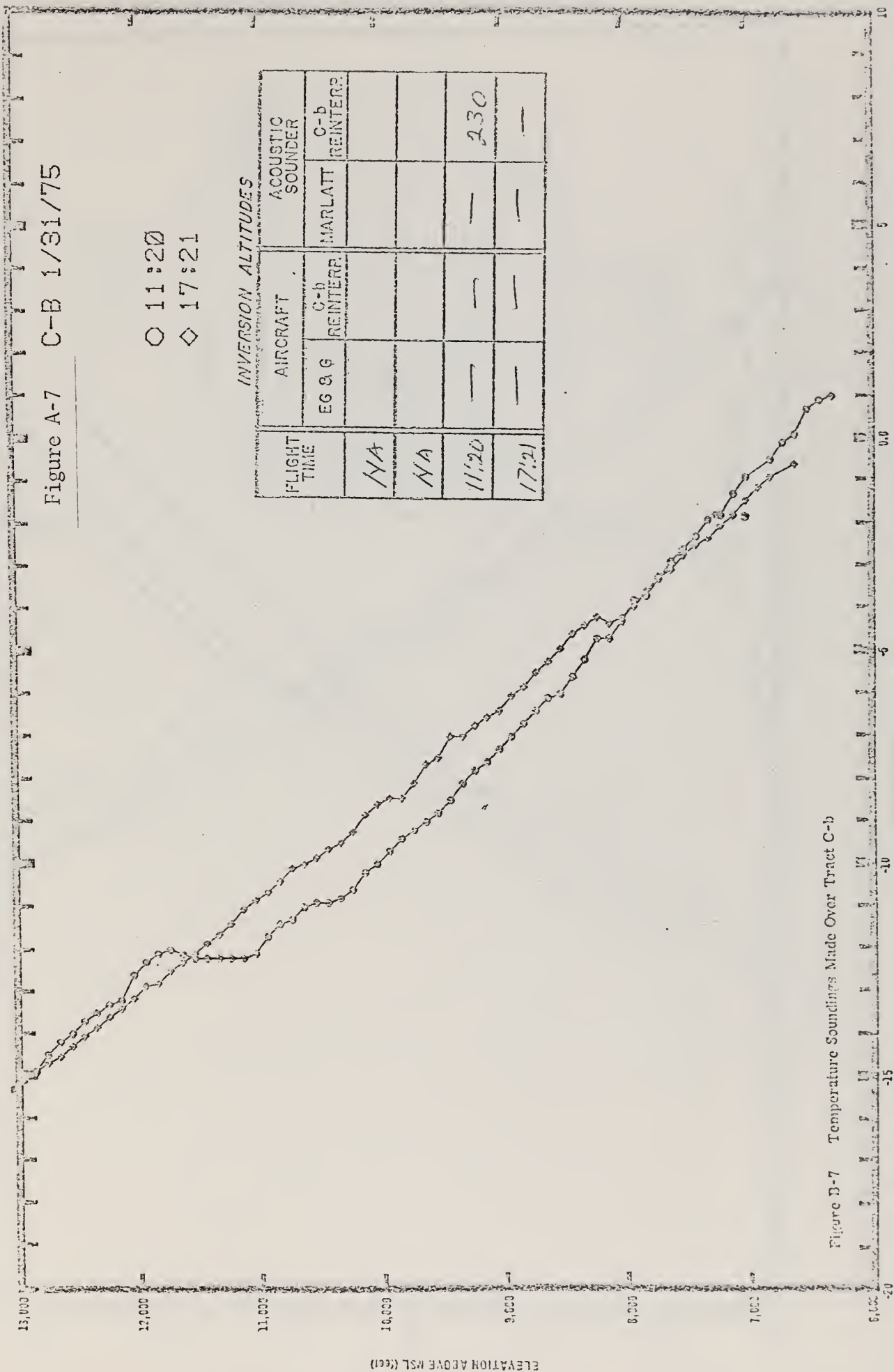


Figure D-7 Temperature Soundings Made Over Tract C-b

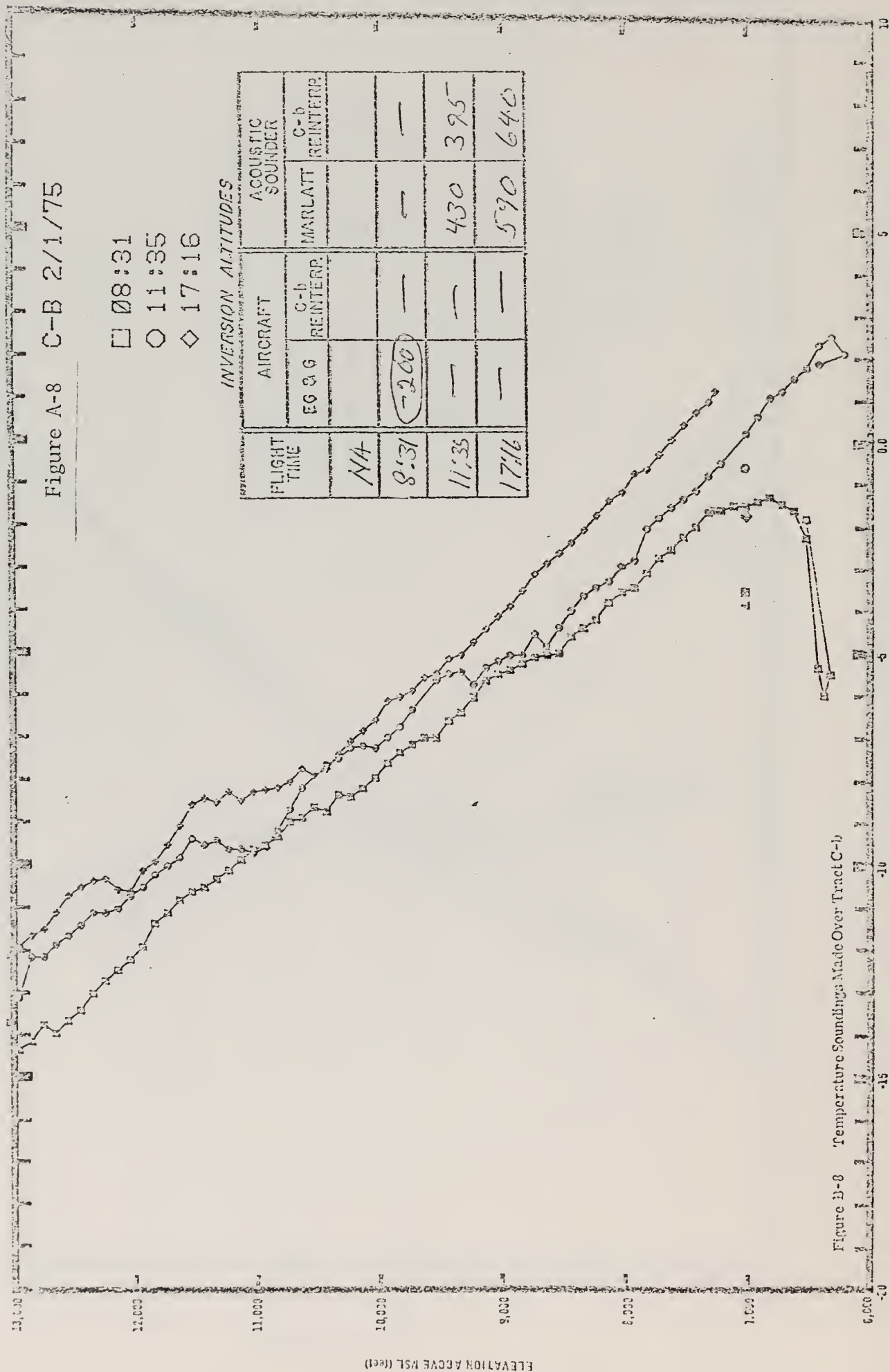
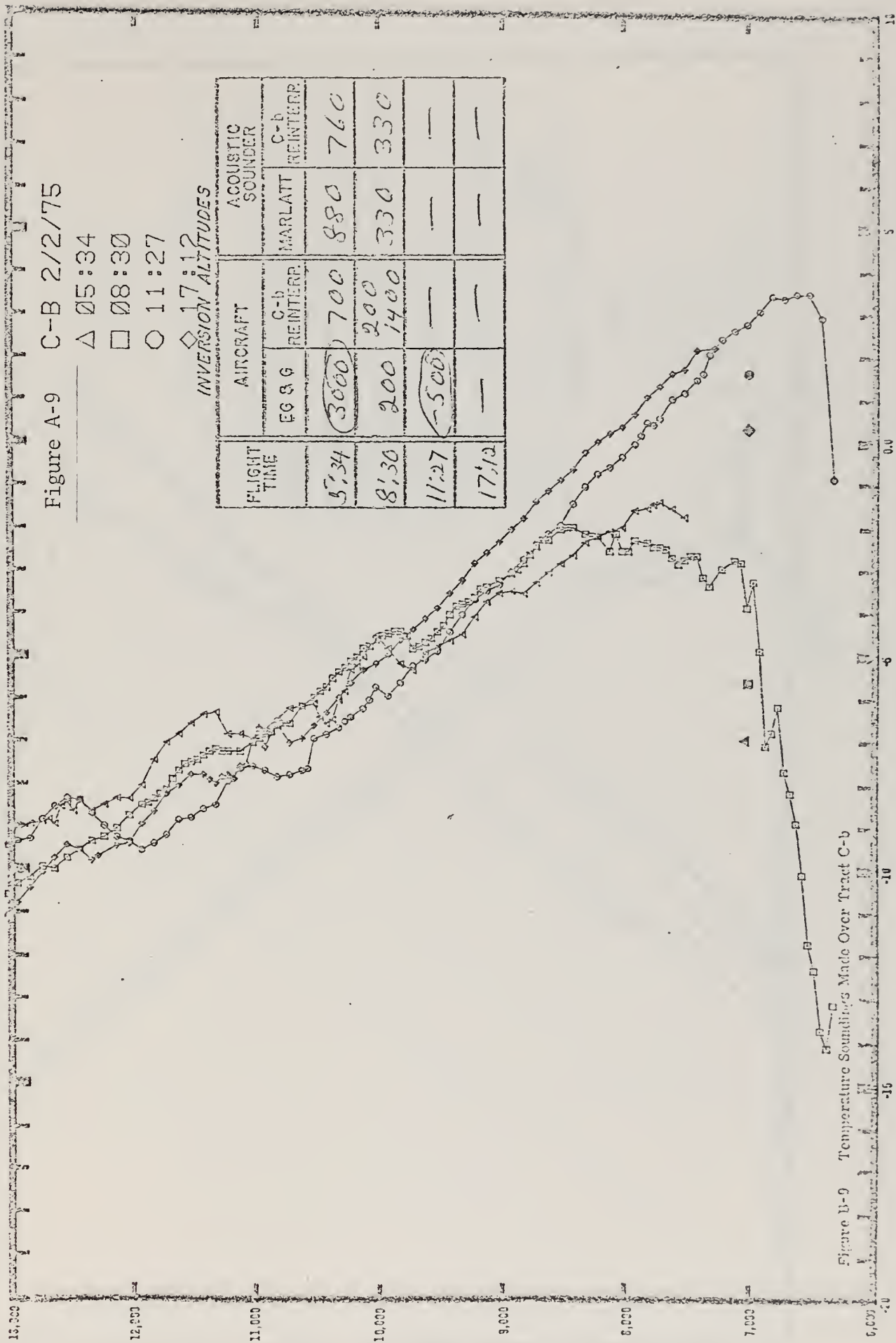
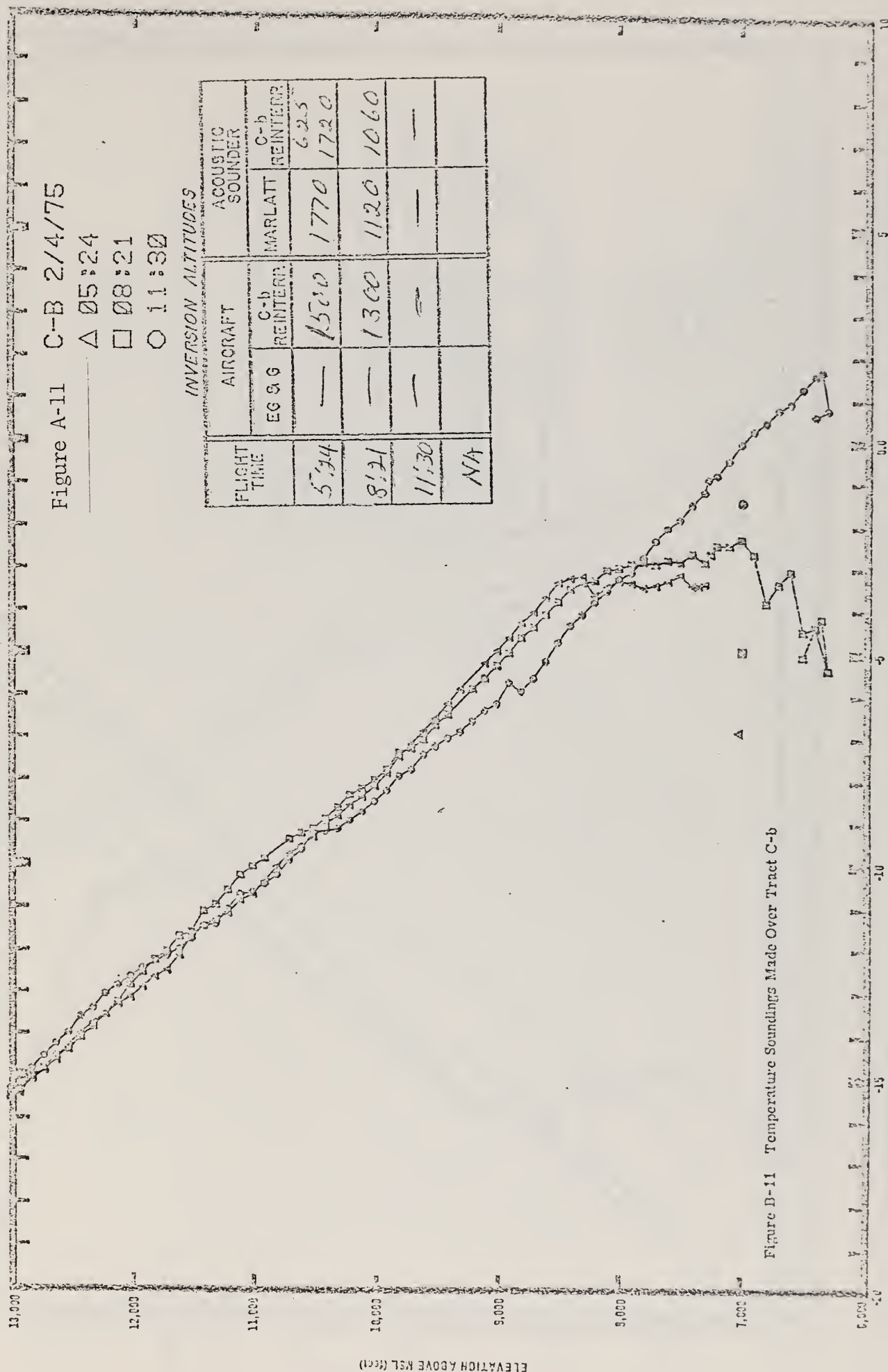


Figure B-8 Temperature Soundings Made Over Tract C-b





ELEVATION ABOVE MSL (feet)

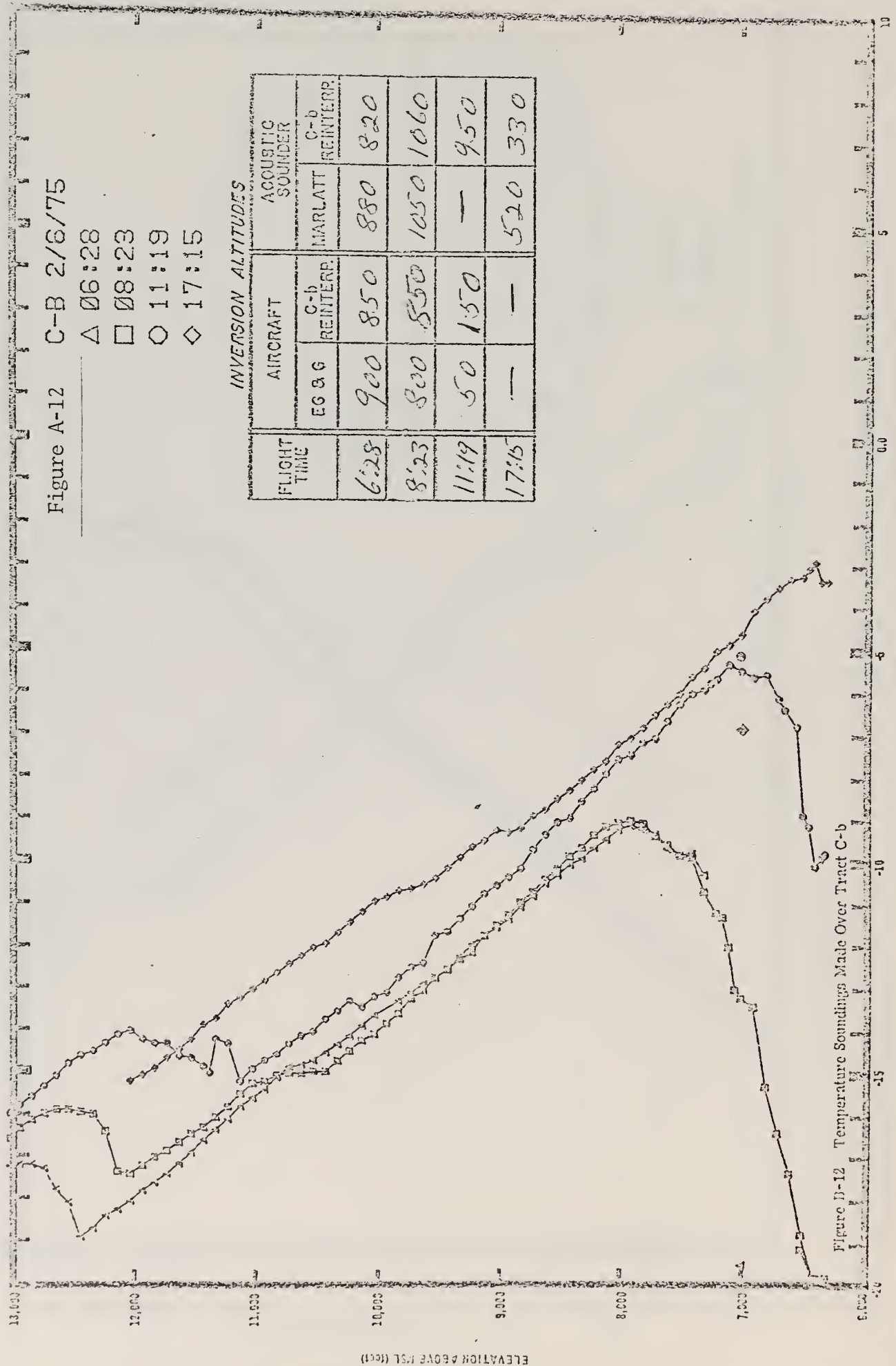


Figure A-12 C-B 2/6/75

△ 06:28
 □ 08:23
 ○ 11:19
 ◇ 17:15

FLIGHT TIME	AIRCRAFT		INVERSION ALTITUDES		ACUSTIC SOUNDER
	EG & G	C-b REINTERP.	MARKLATT	C-b REINTERP.	
6:28	900	850	880	820	
8:23	800	850	1050	1060	
11:19	50	150	—	950	
17:15	—	—	520	330	

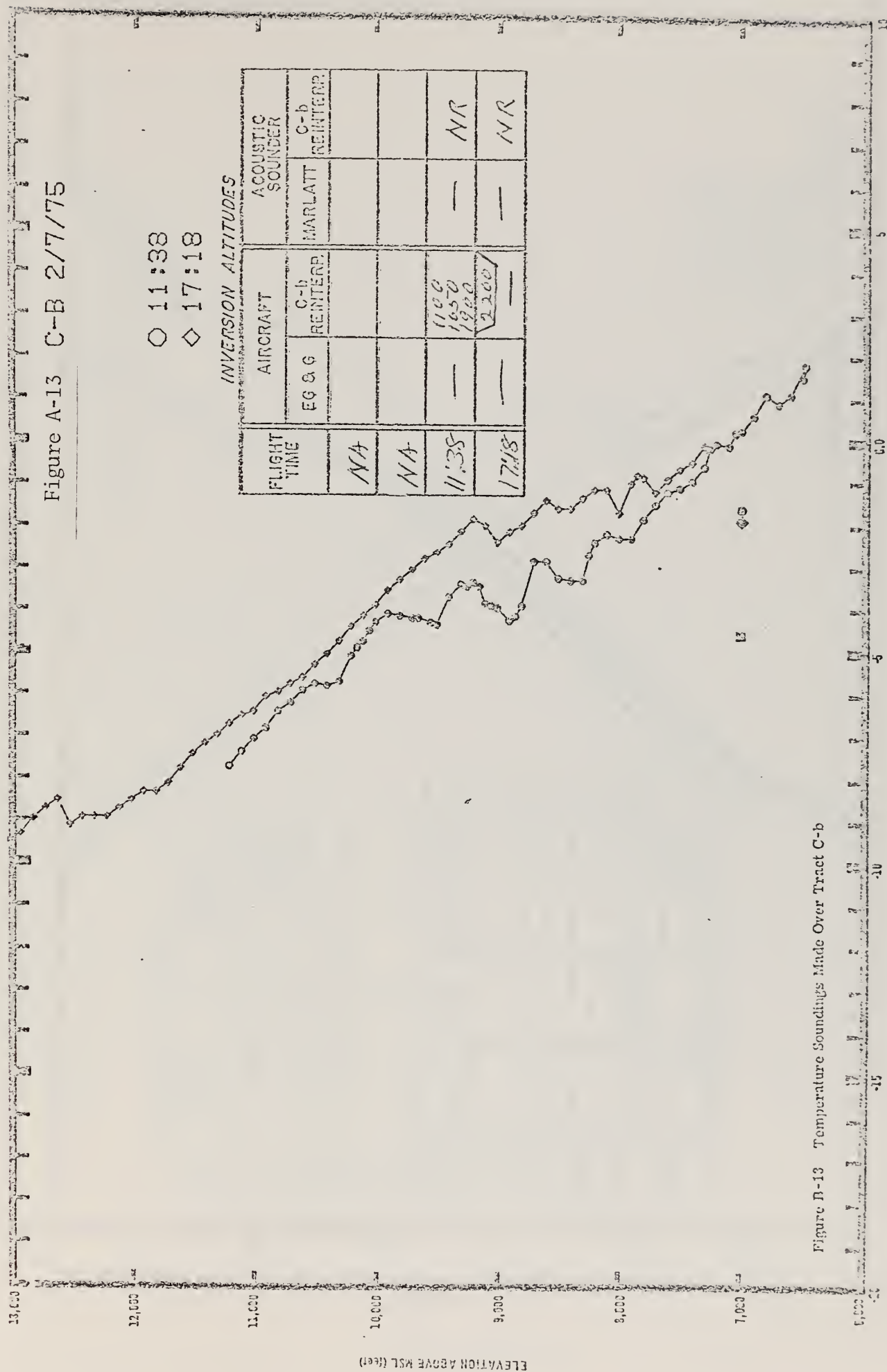


Figure B-13 Temperature Soundings Made Over Tract C-b

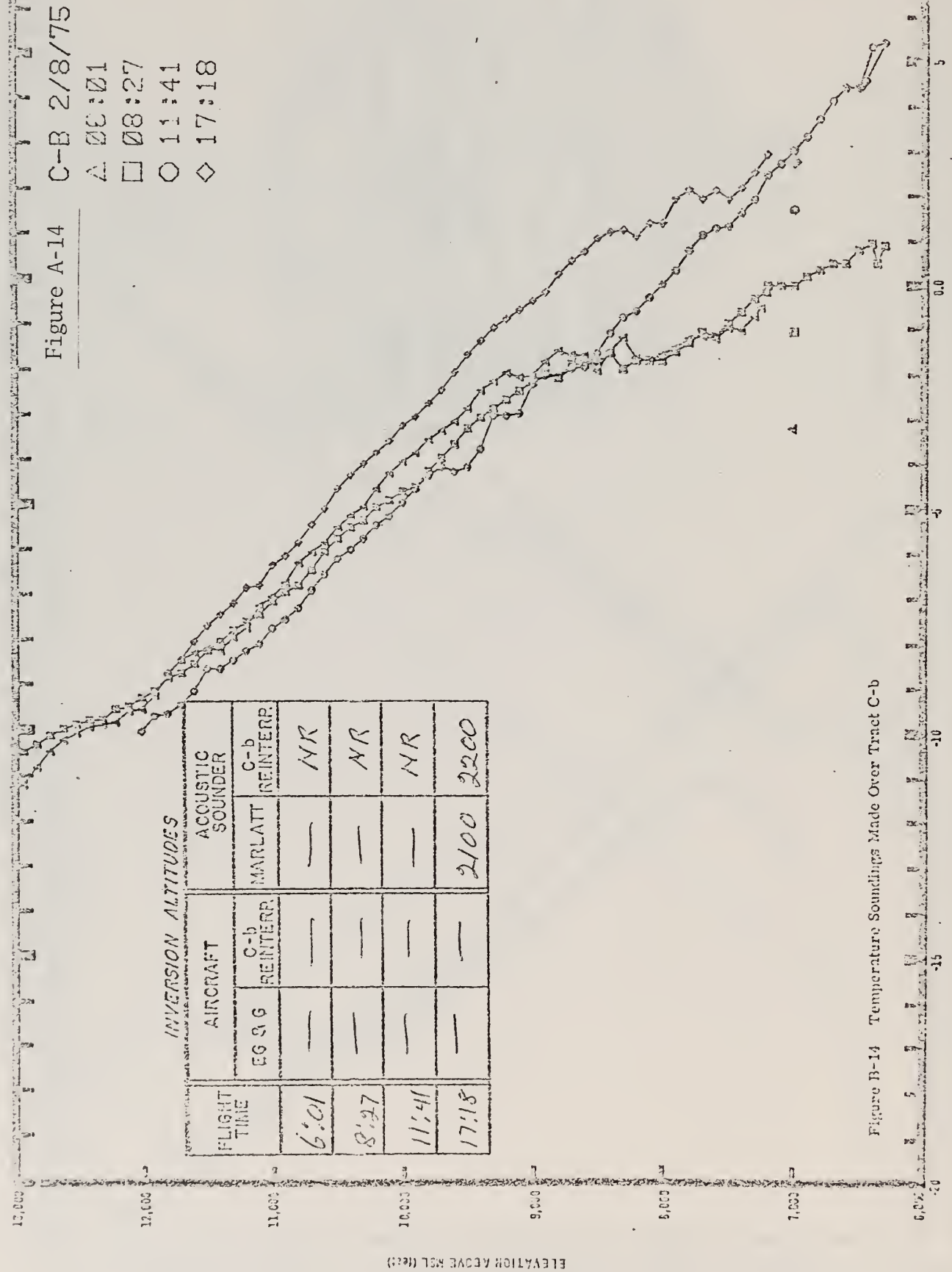


Figure B-14 Temperature Soundings Made Over Tract C-b

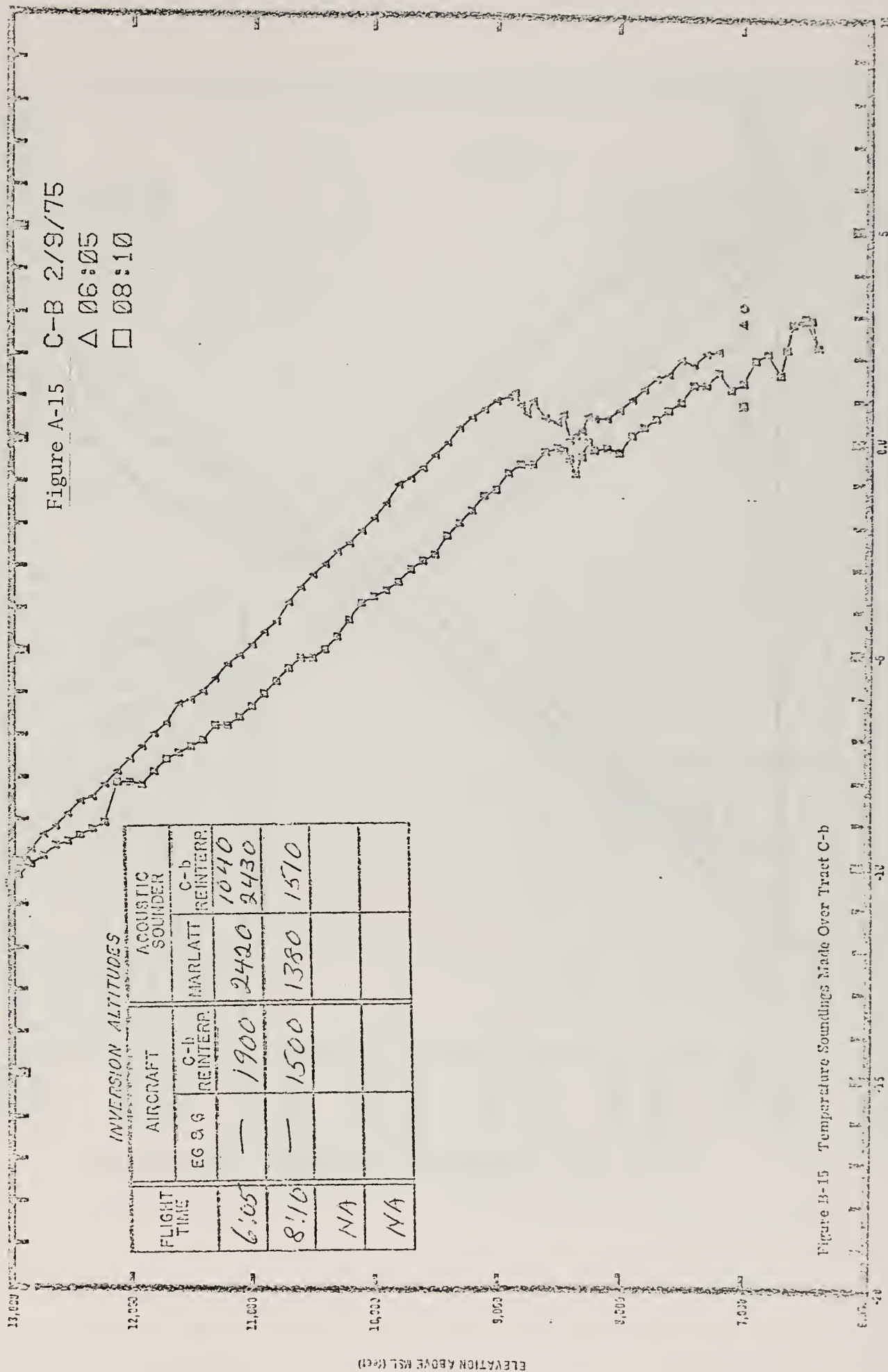
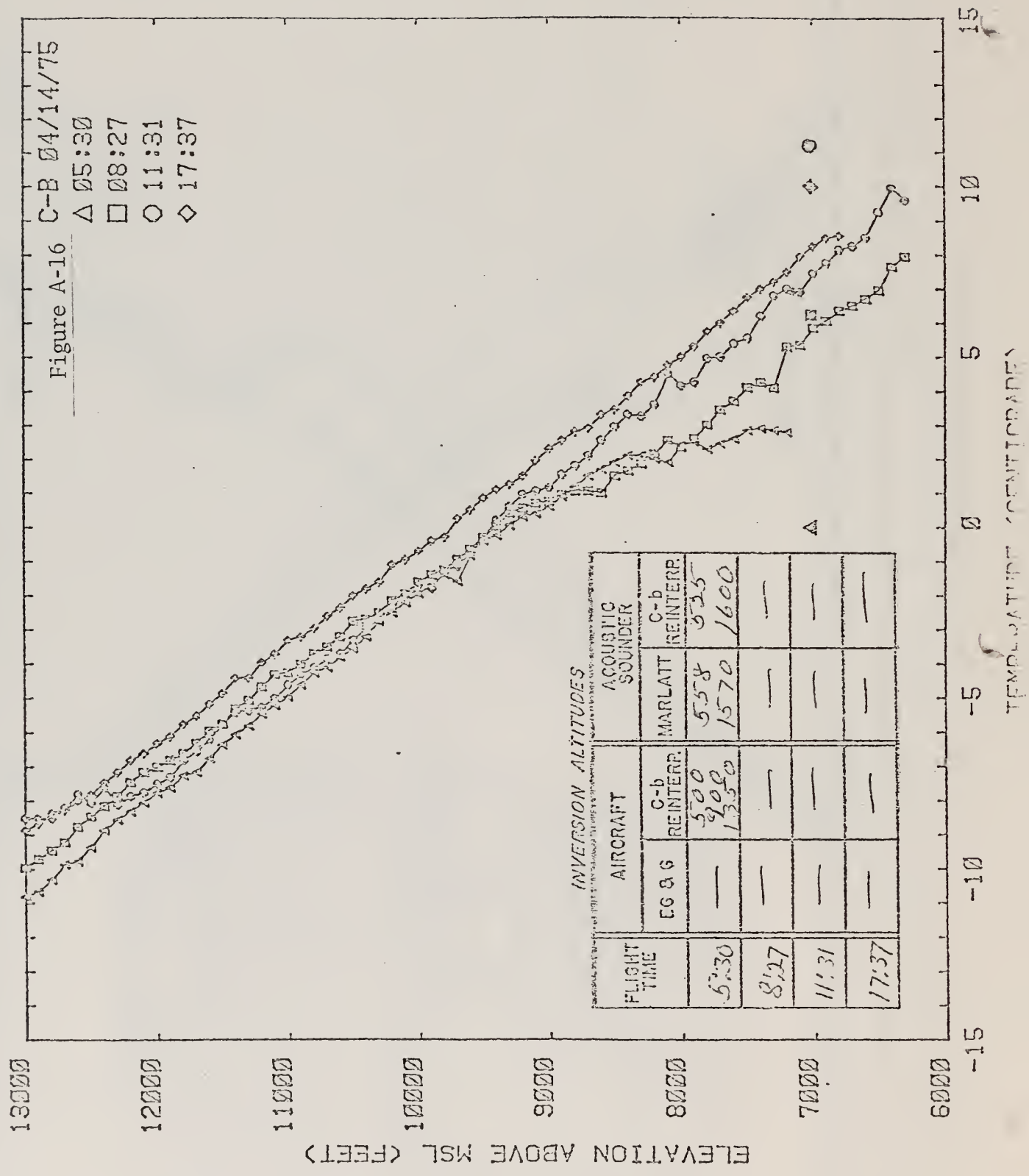
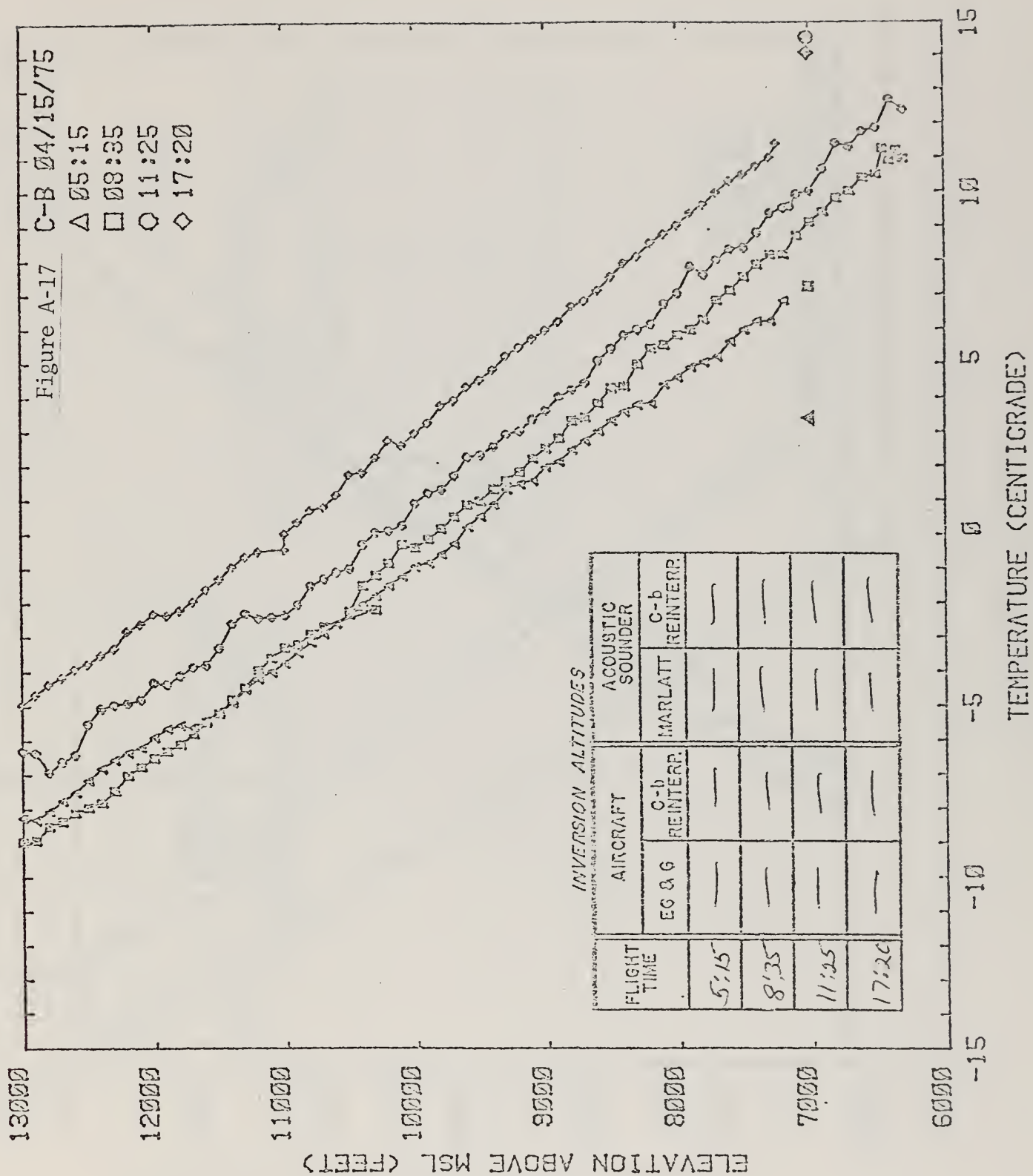
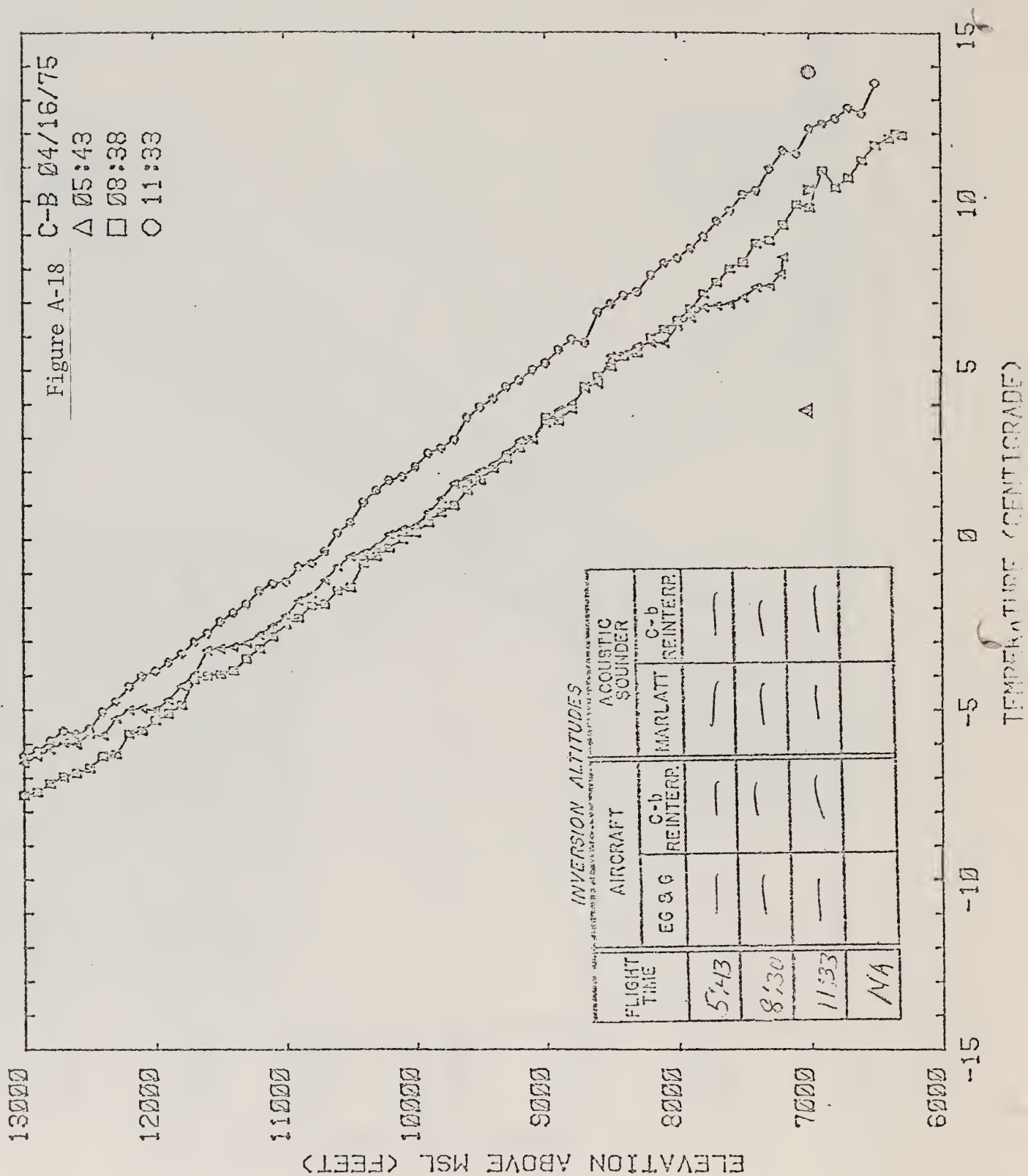
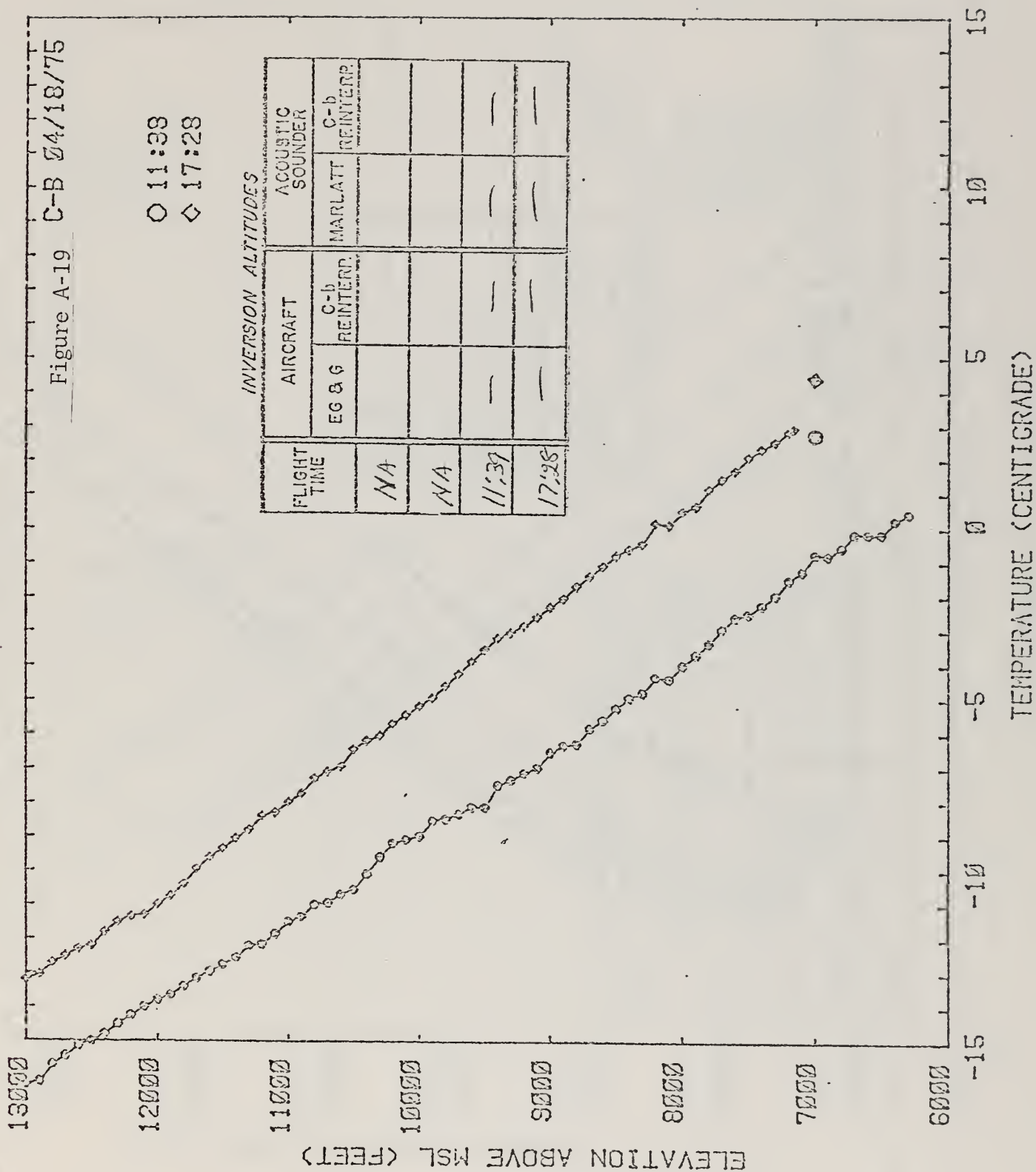


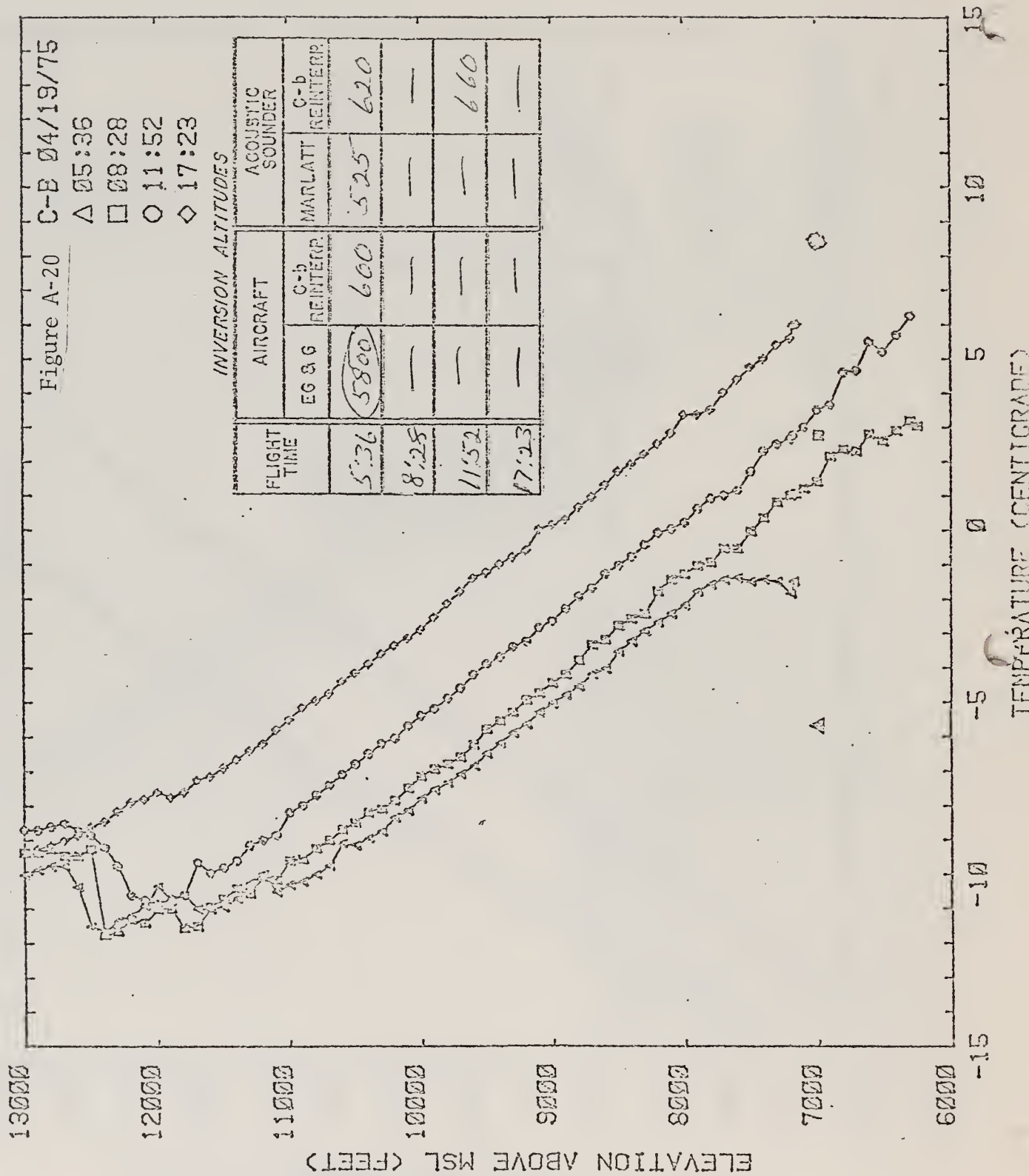
Figure B-15 Temperature Soundings Made Over Tract C-b

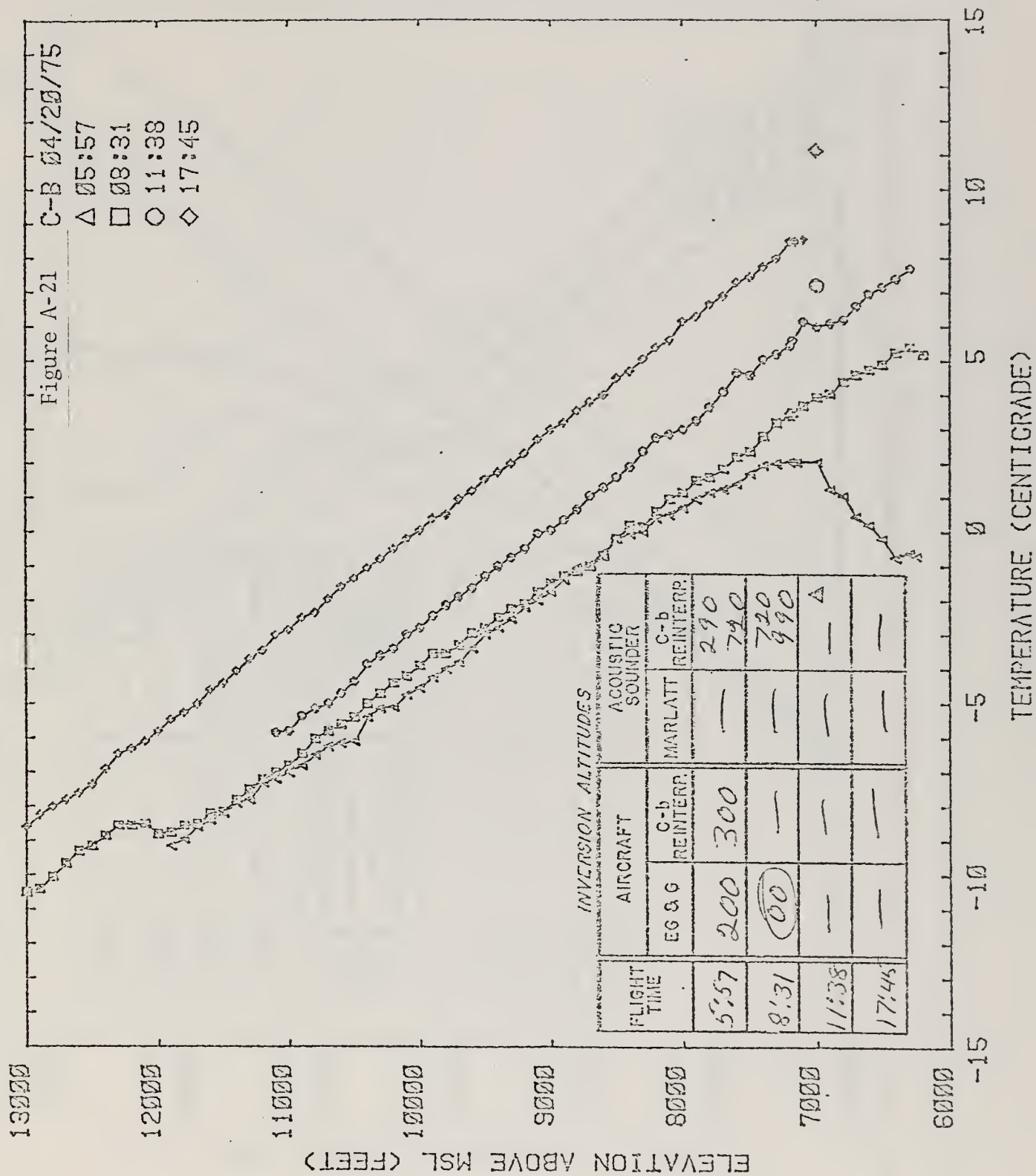


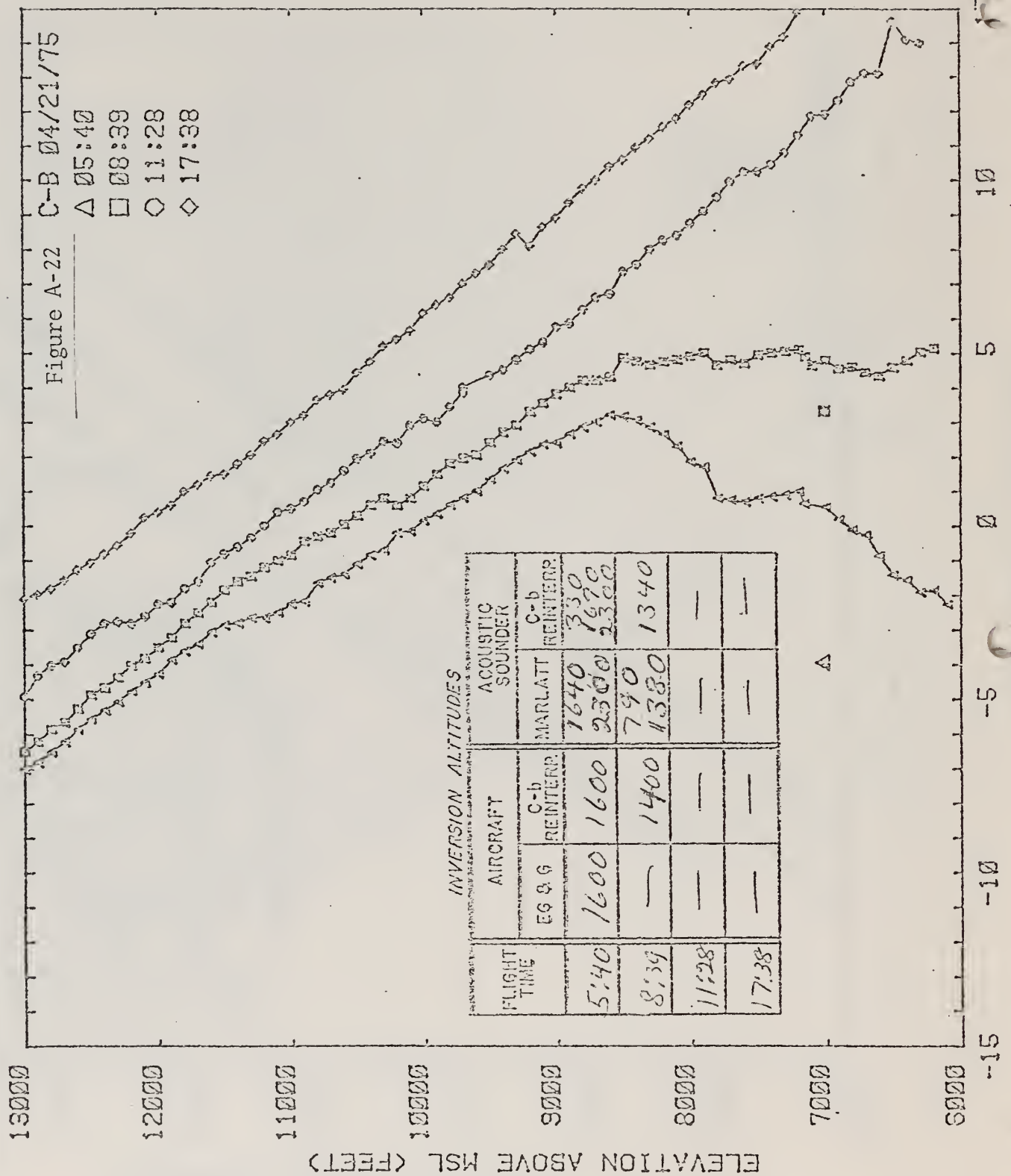


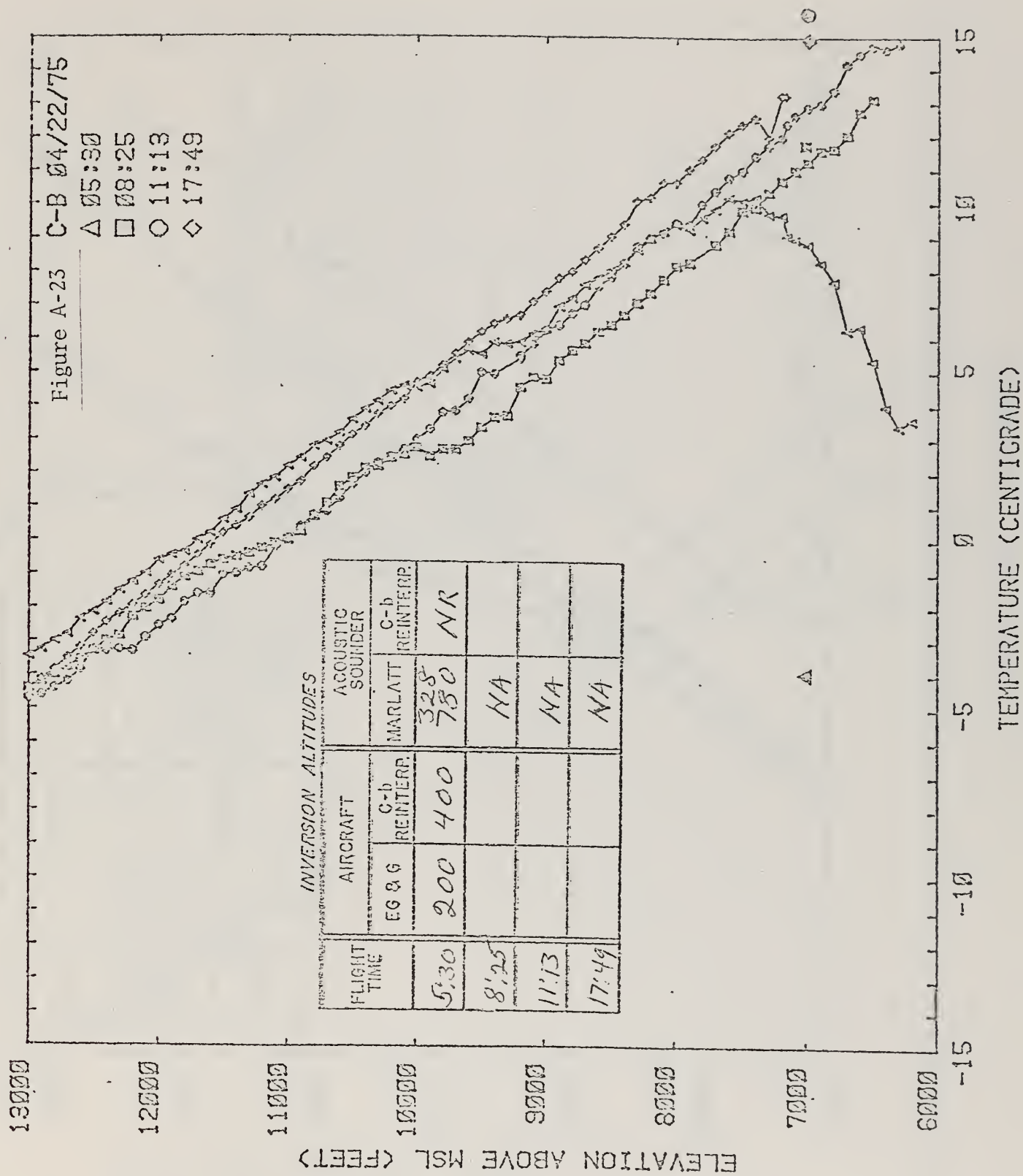


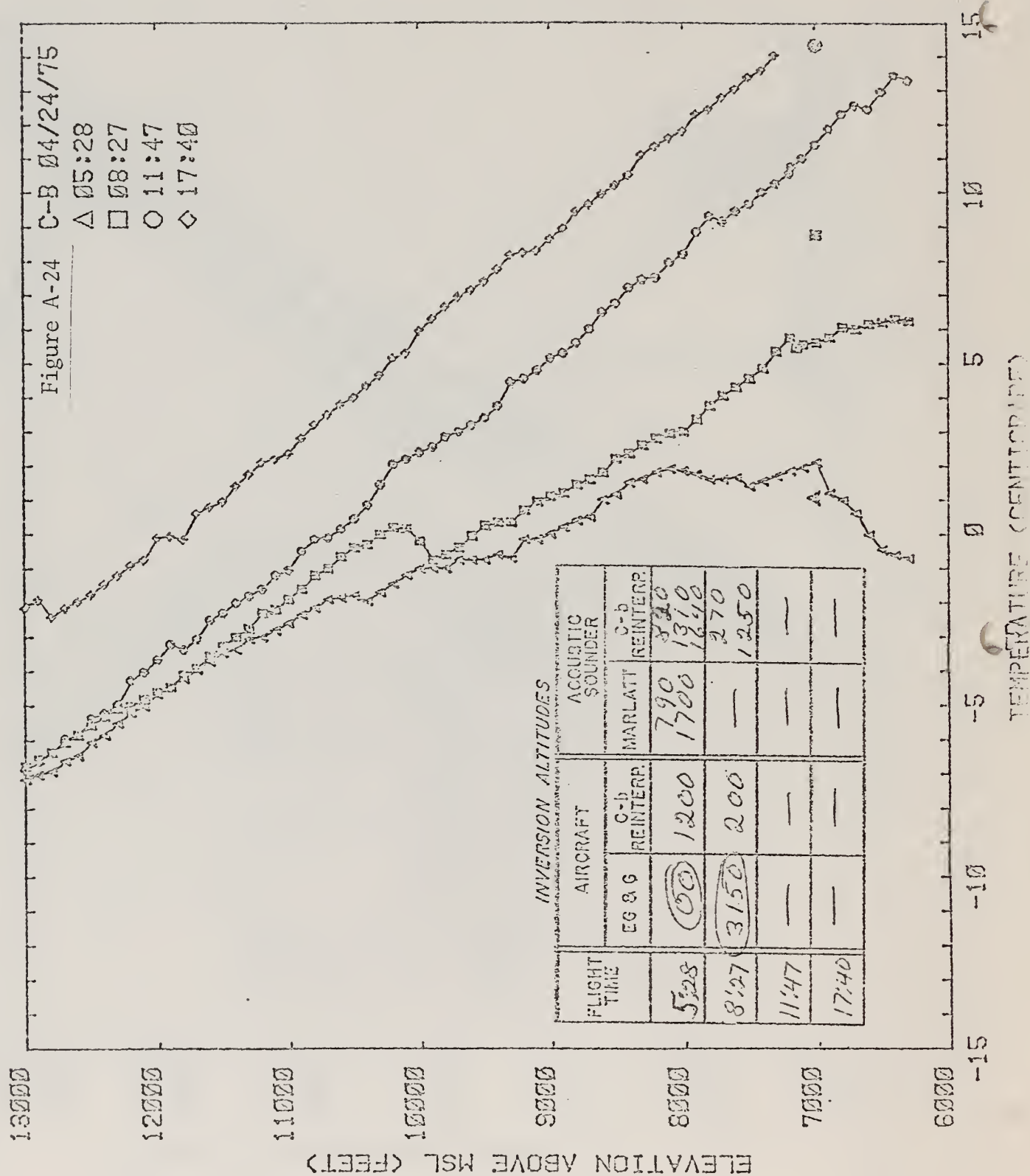


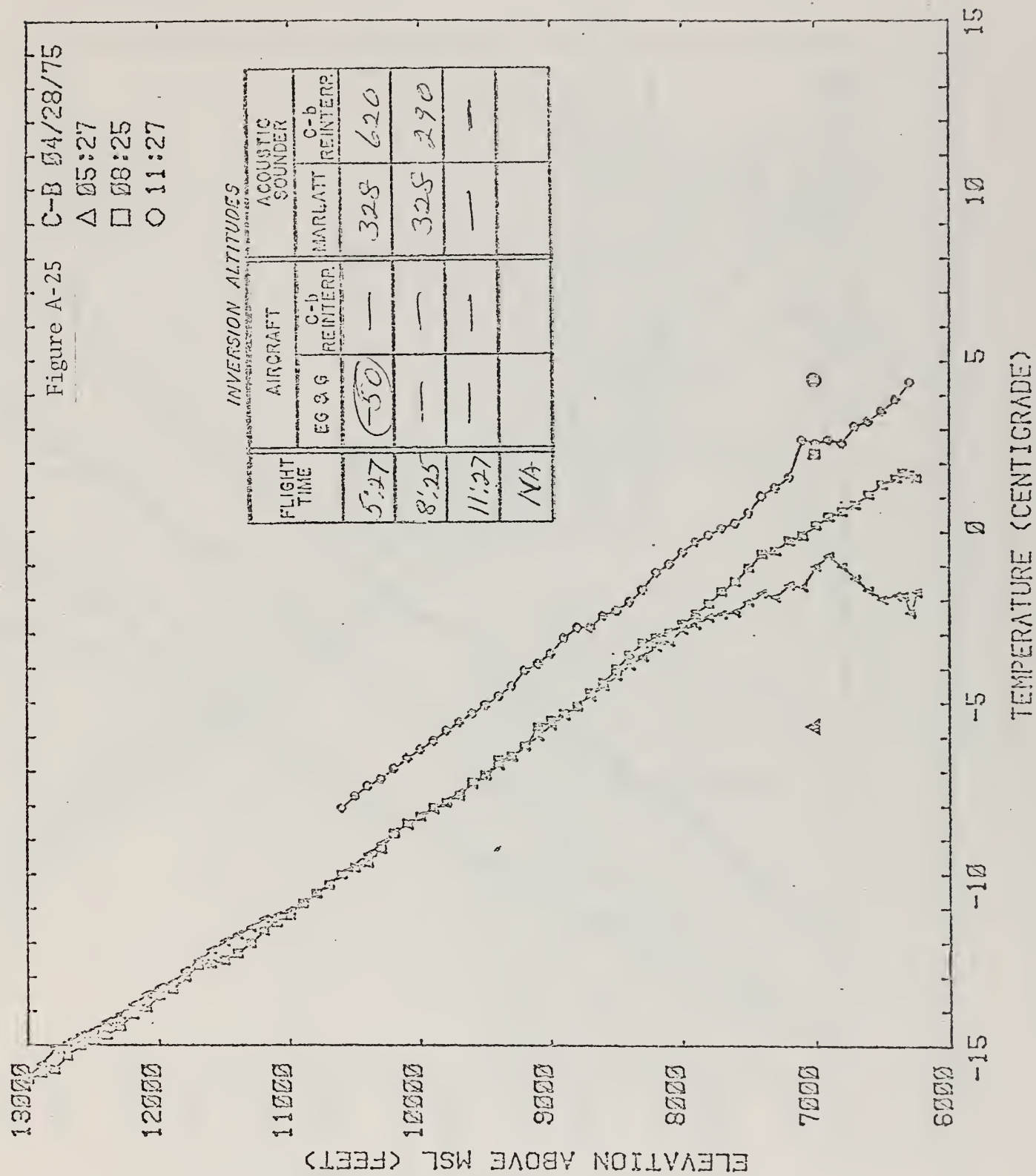


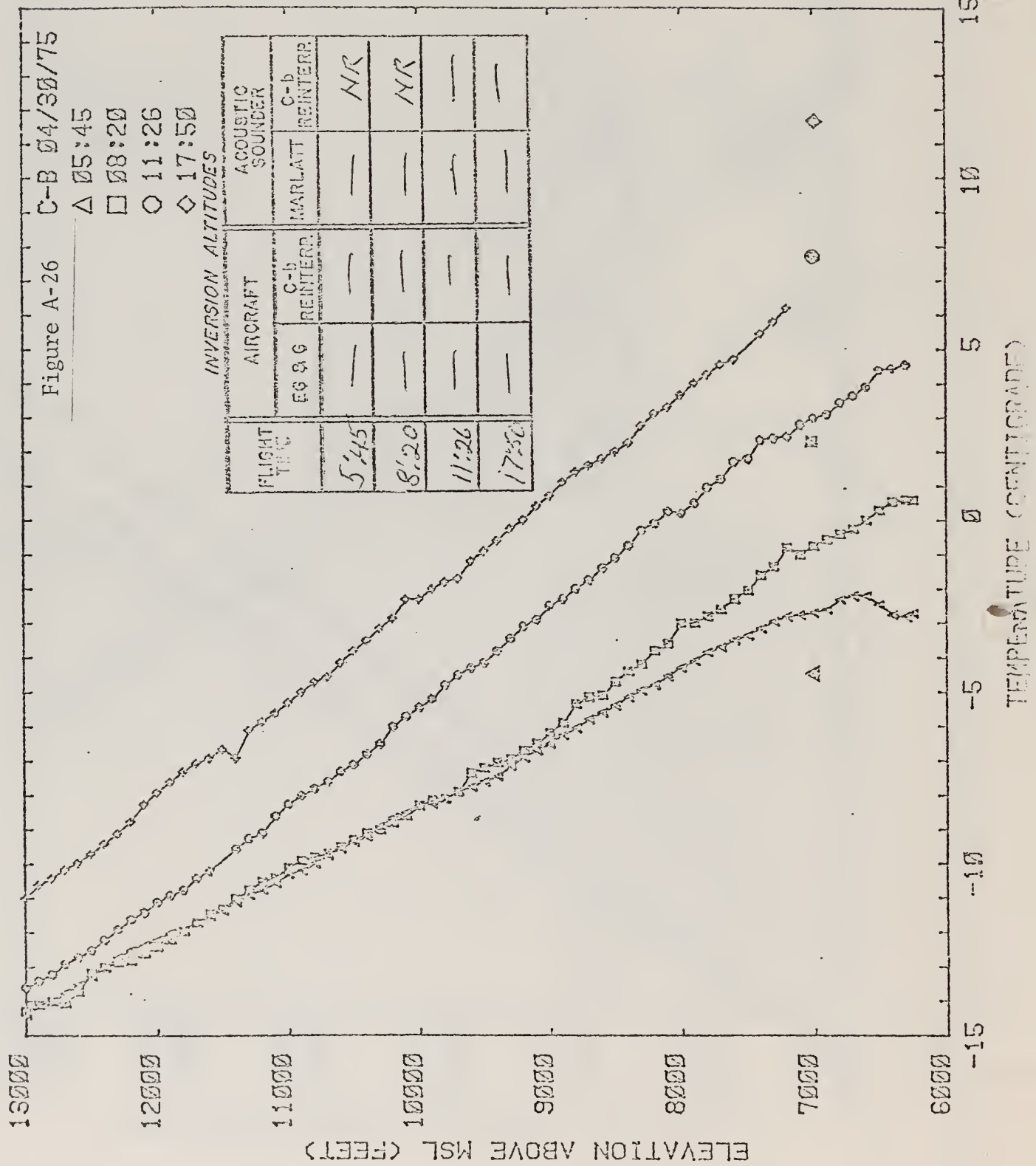


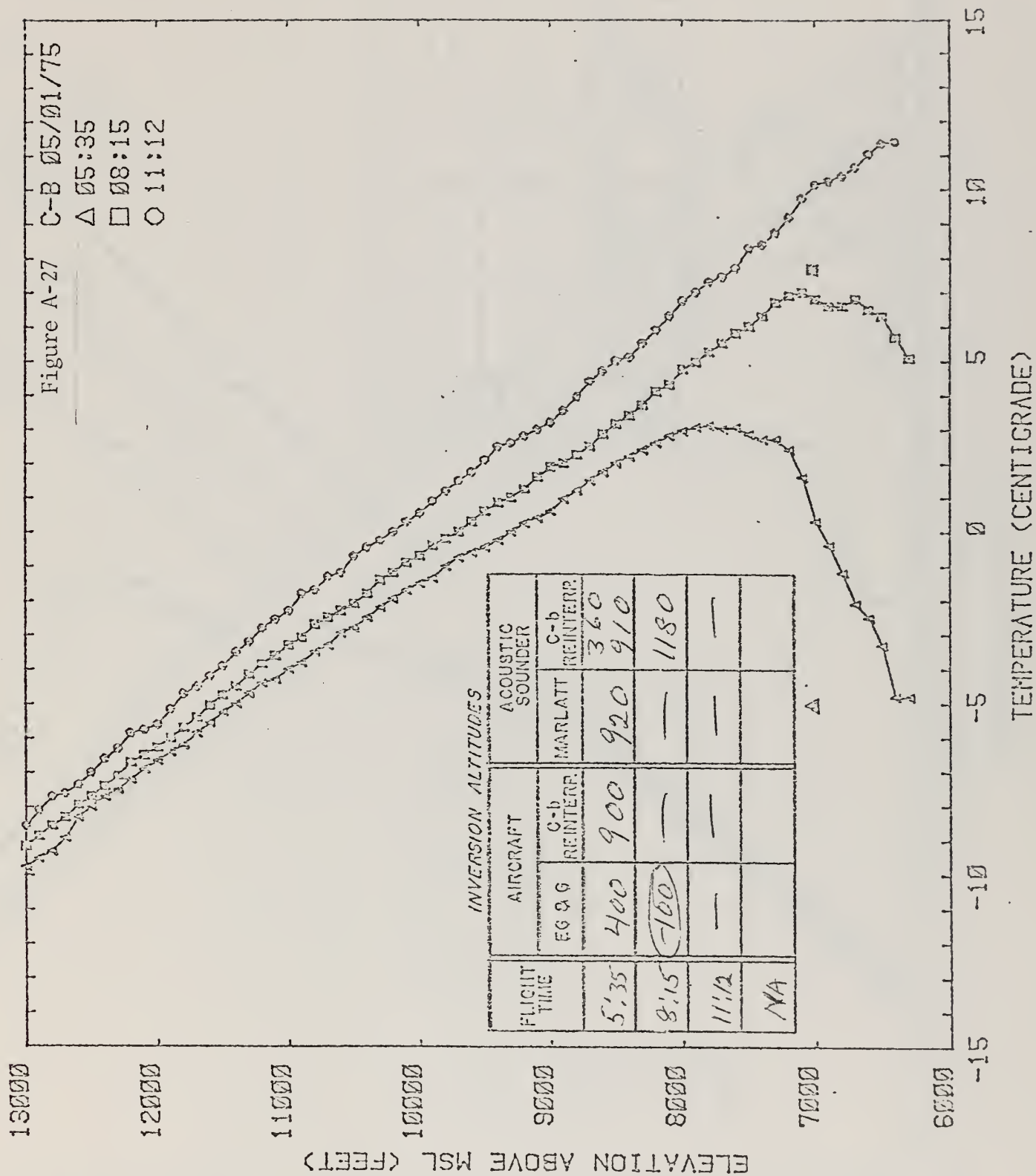


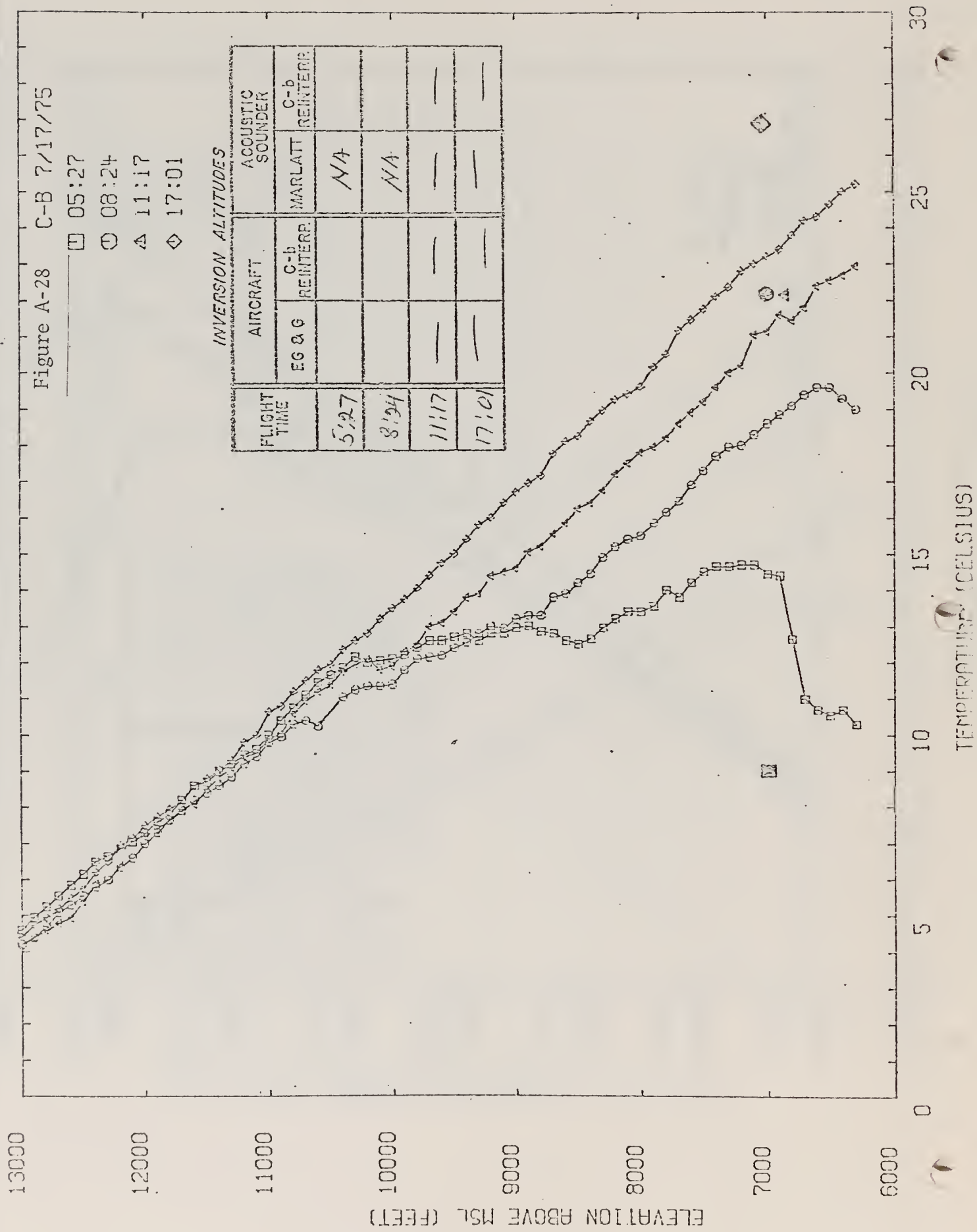


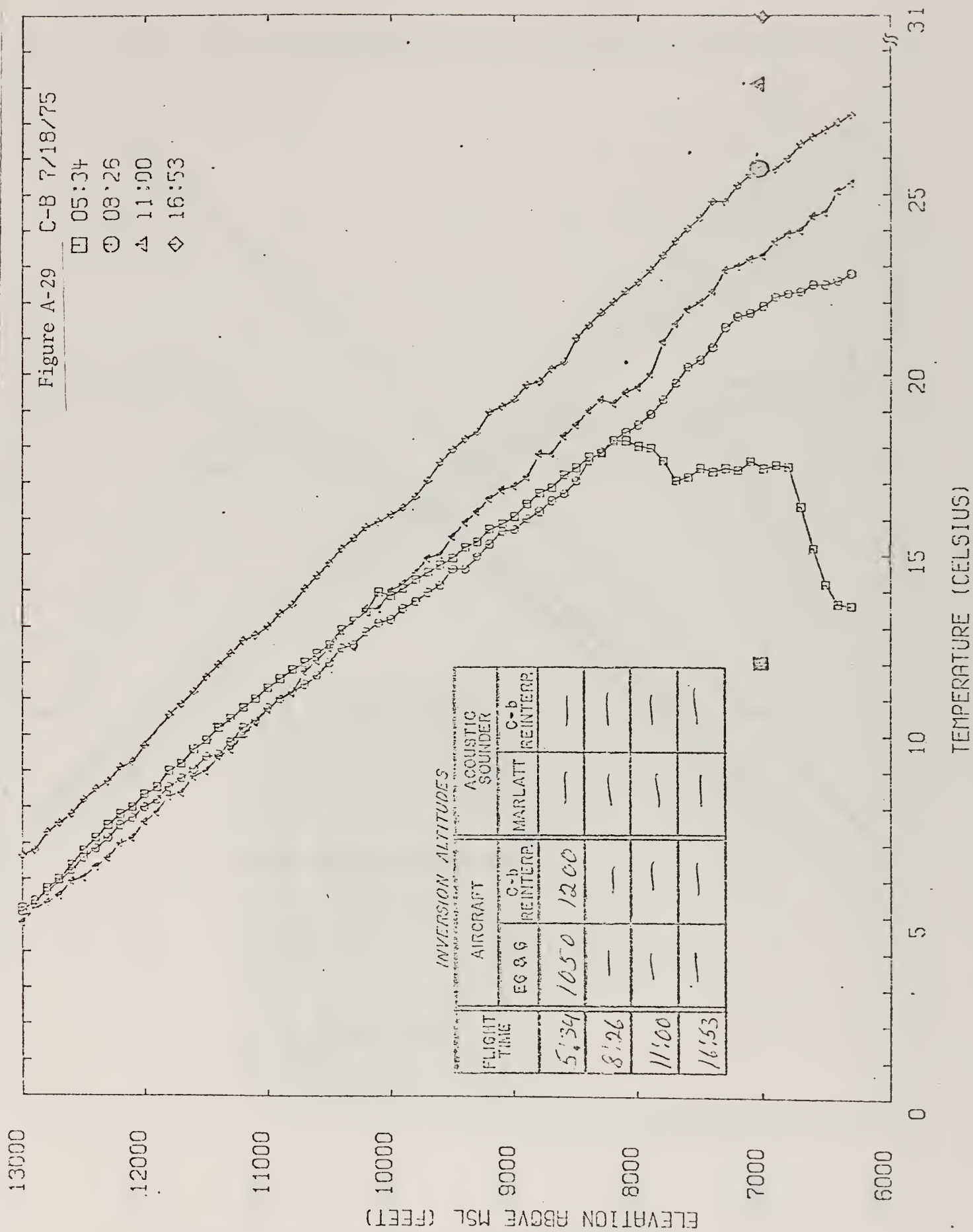


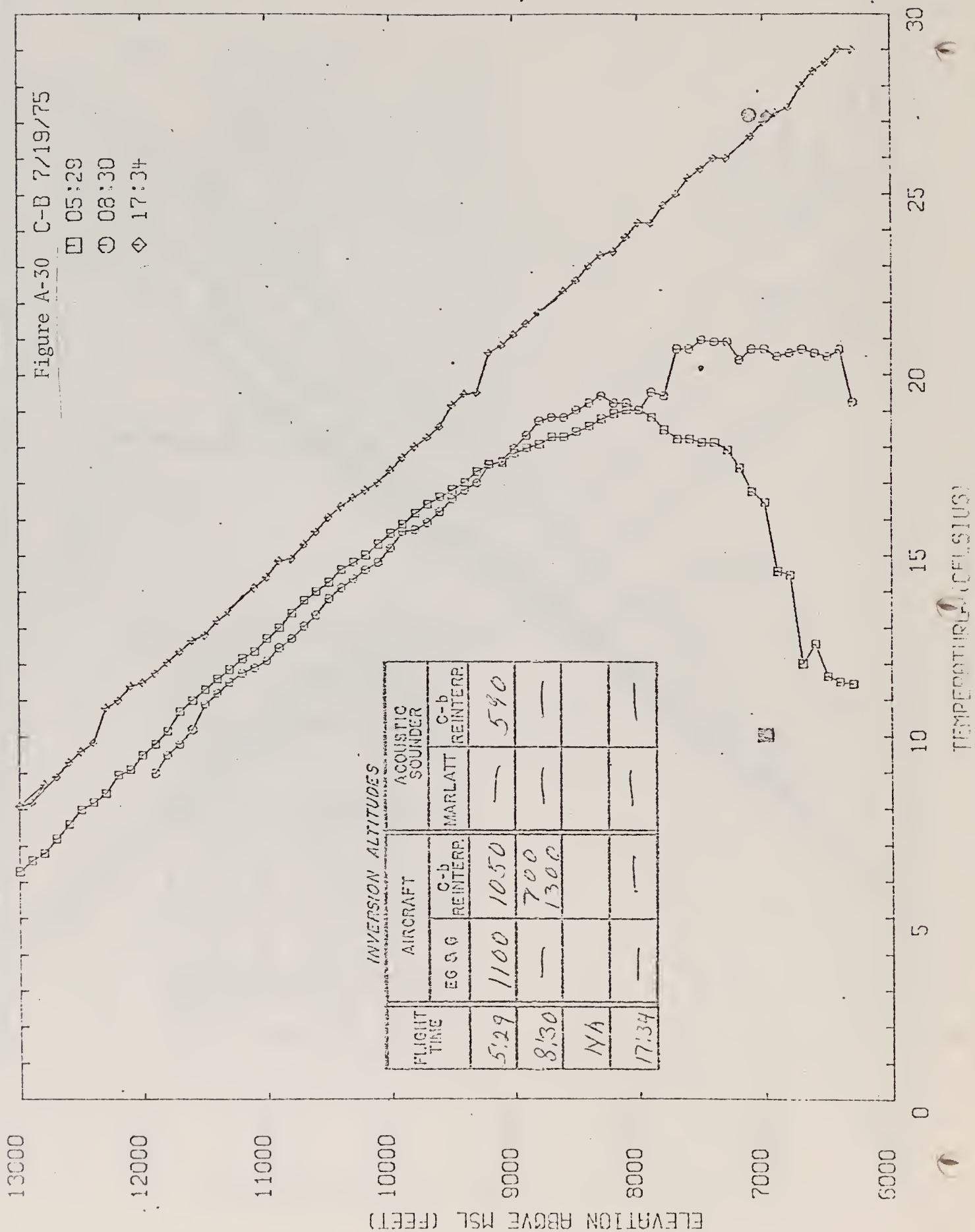


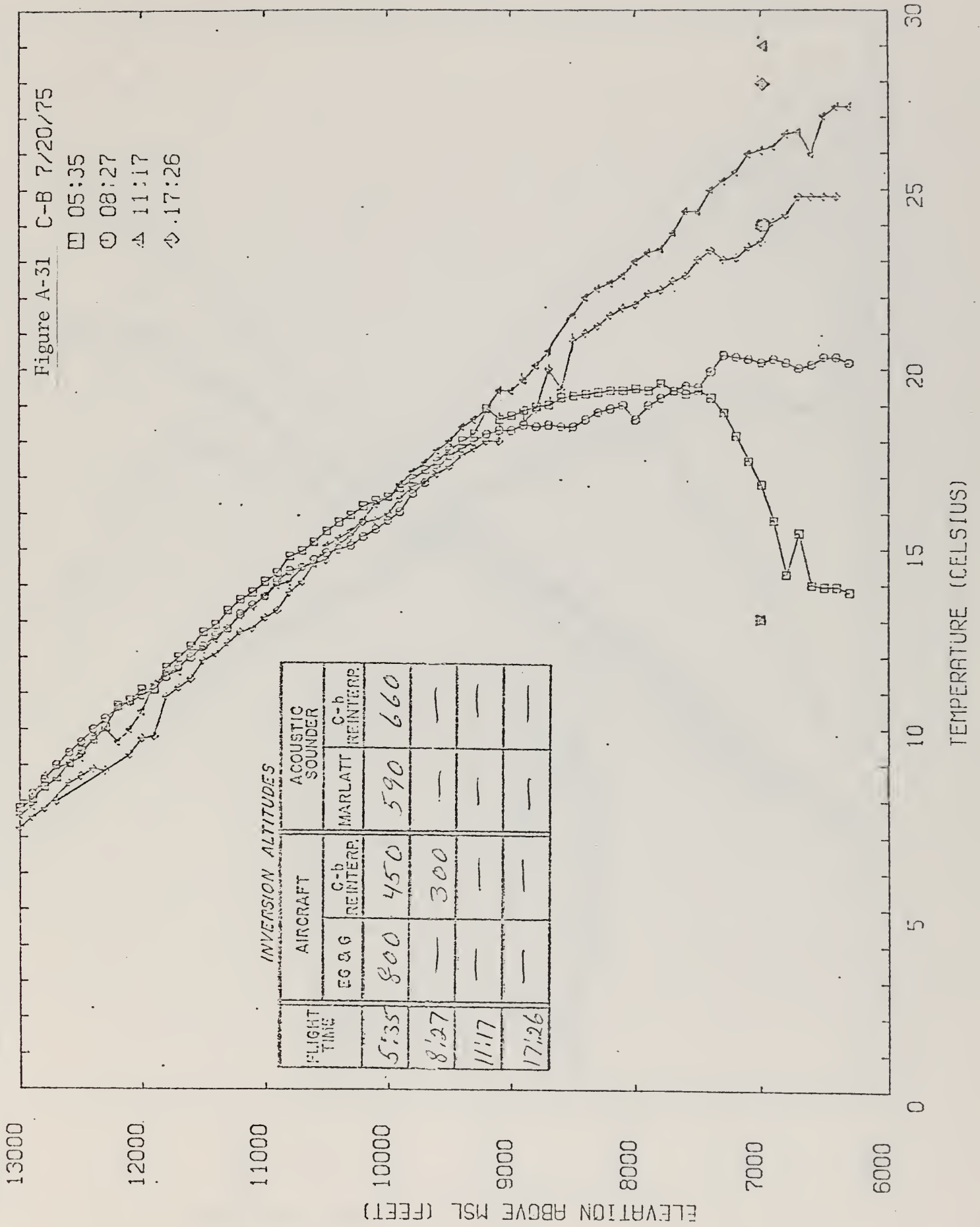


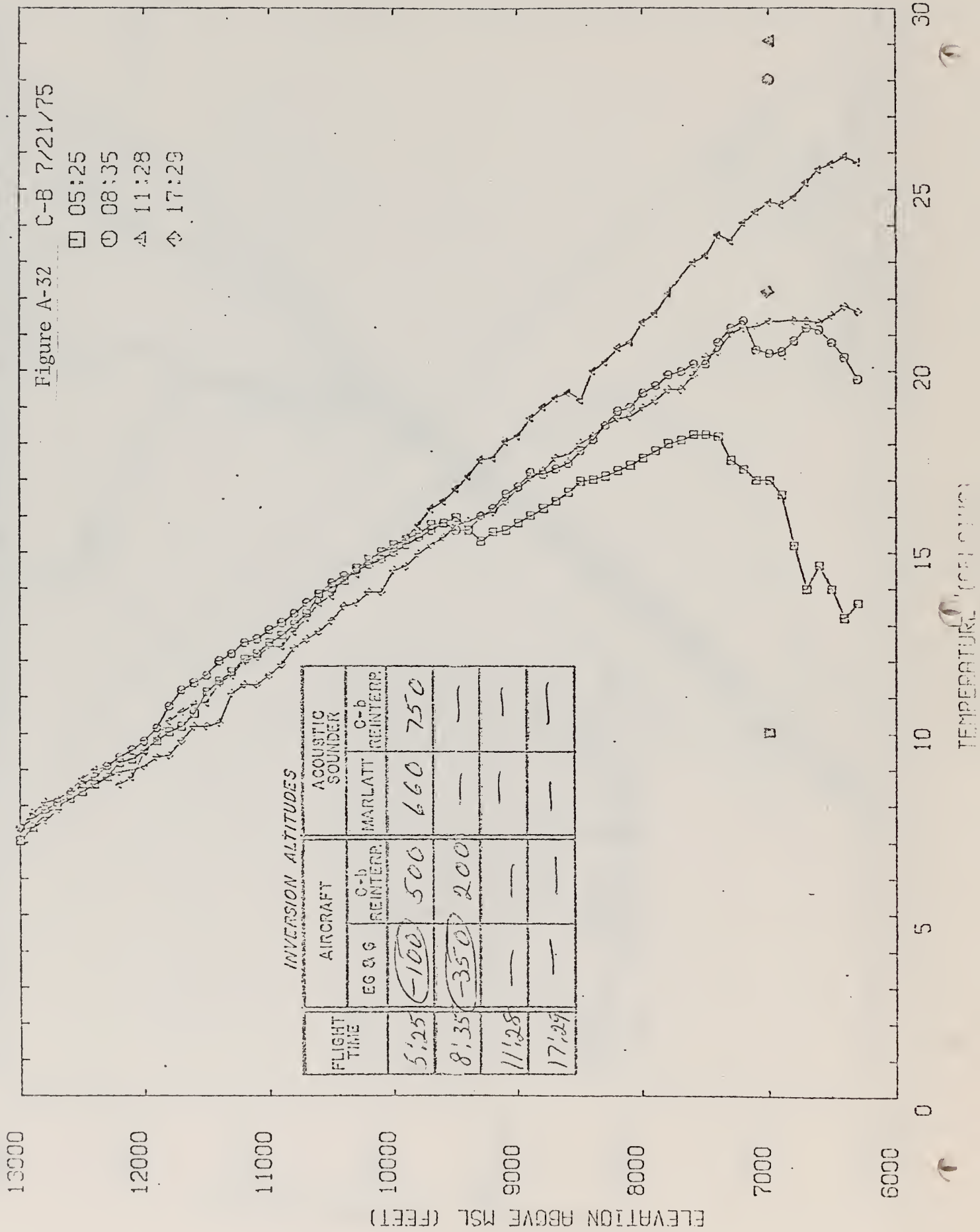


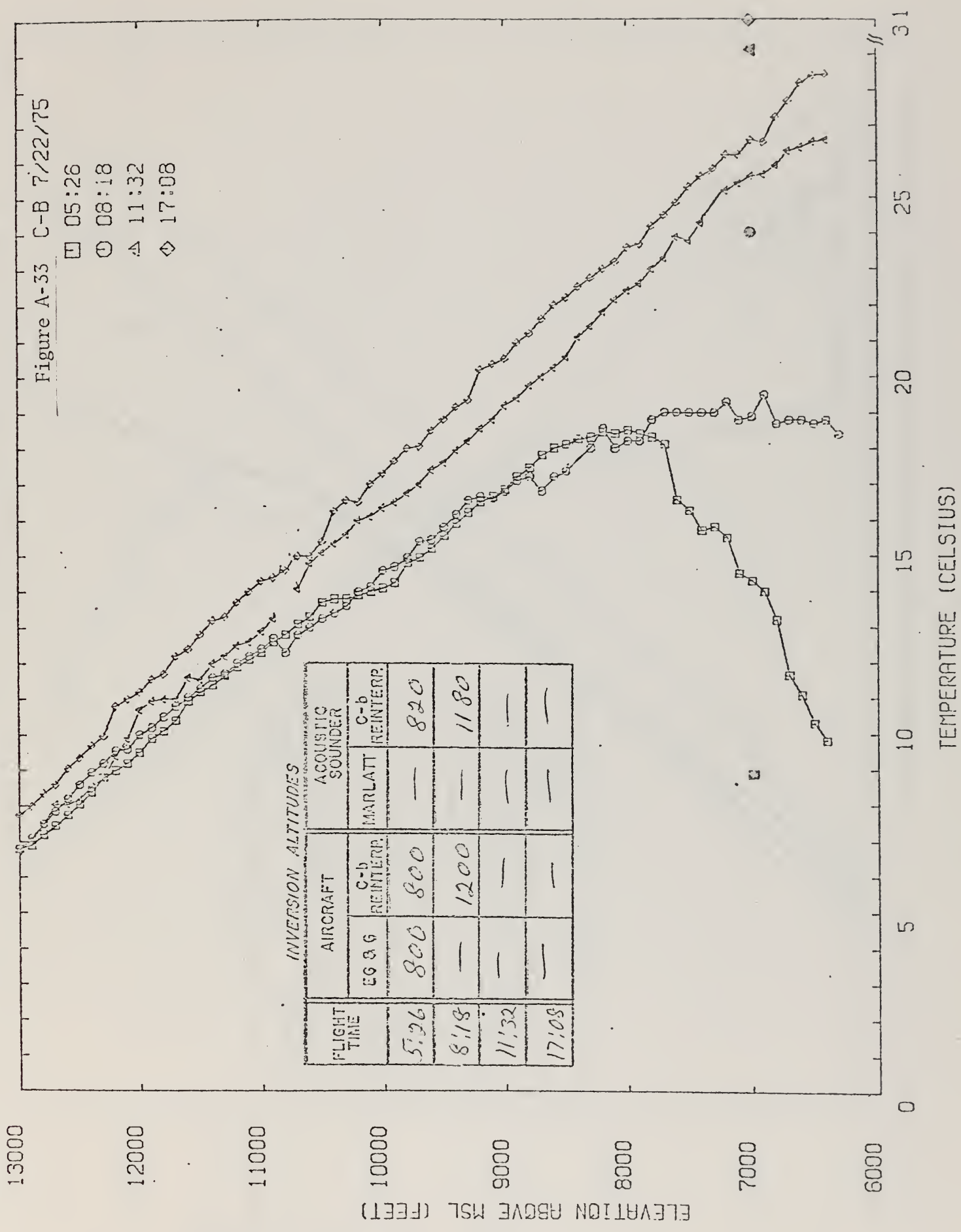


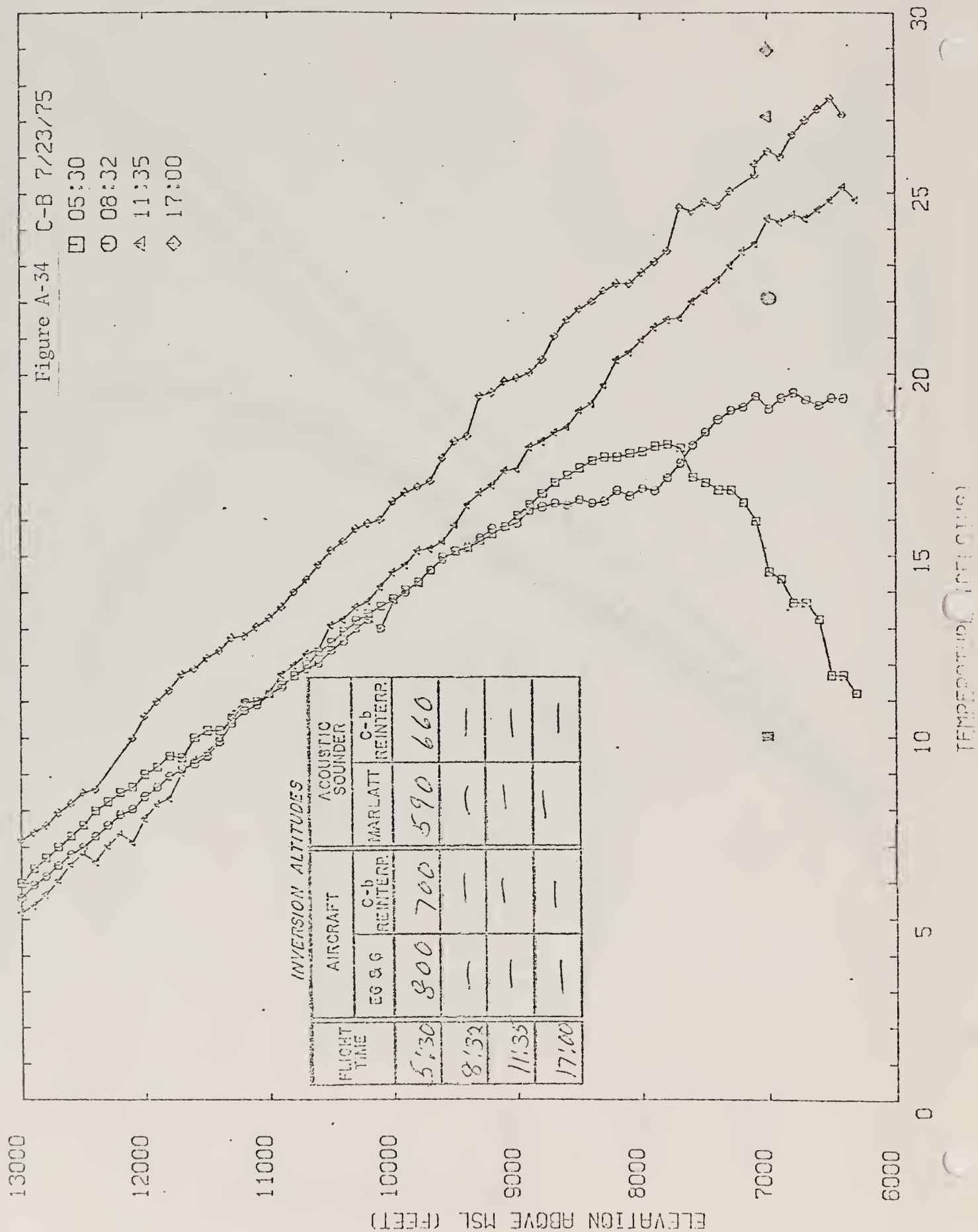


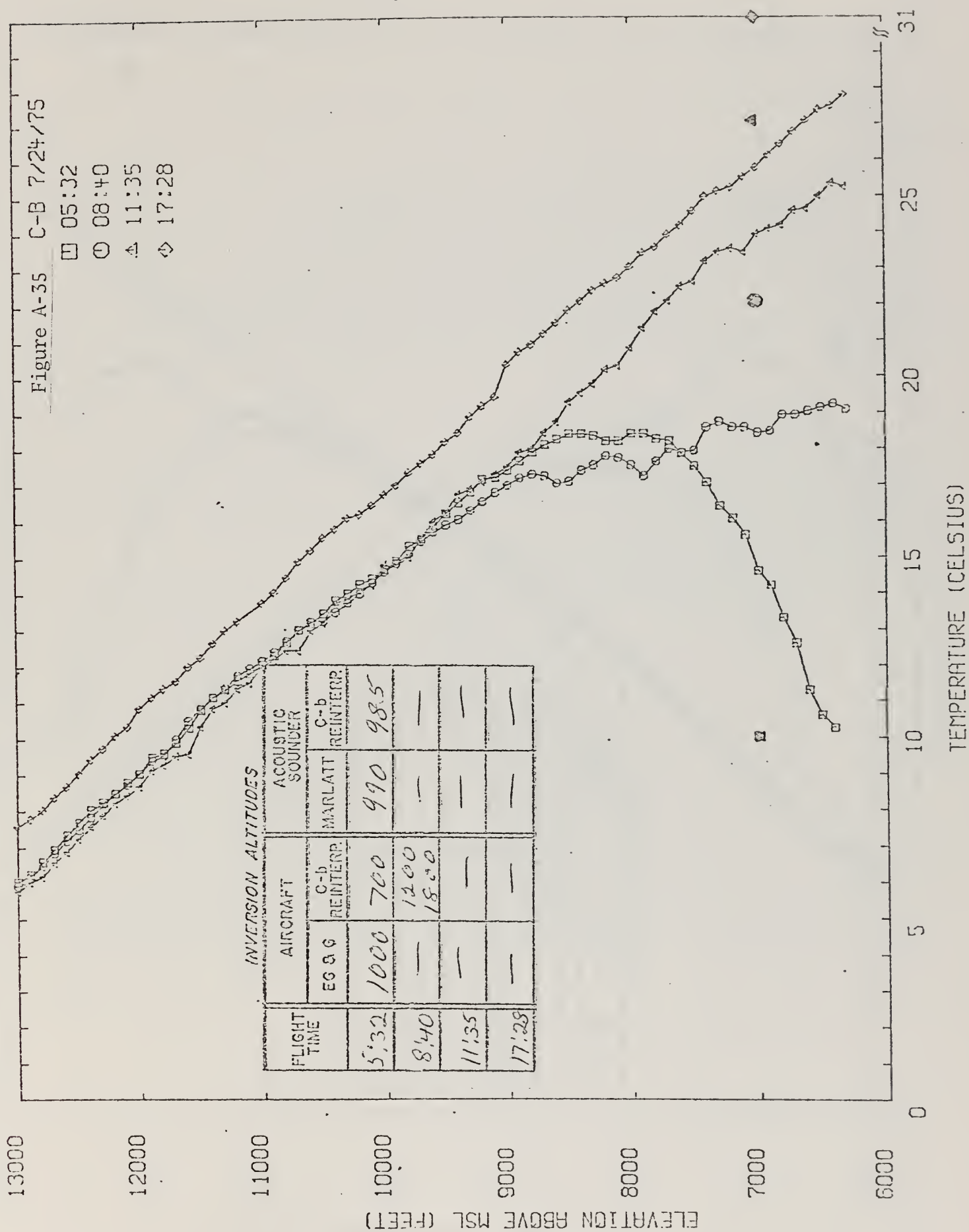












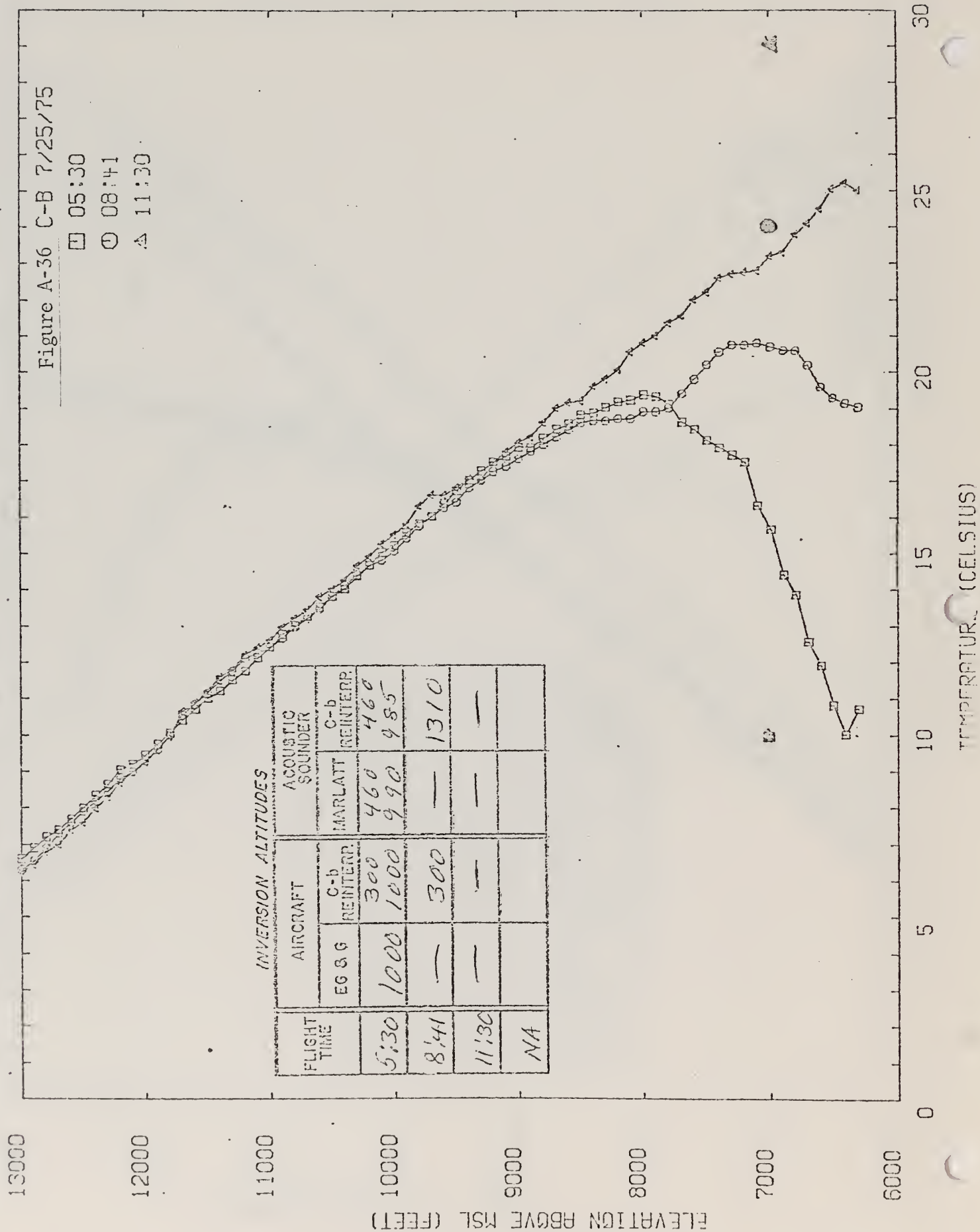
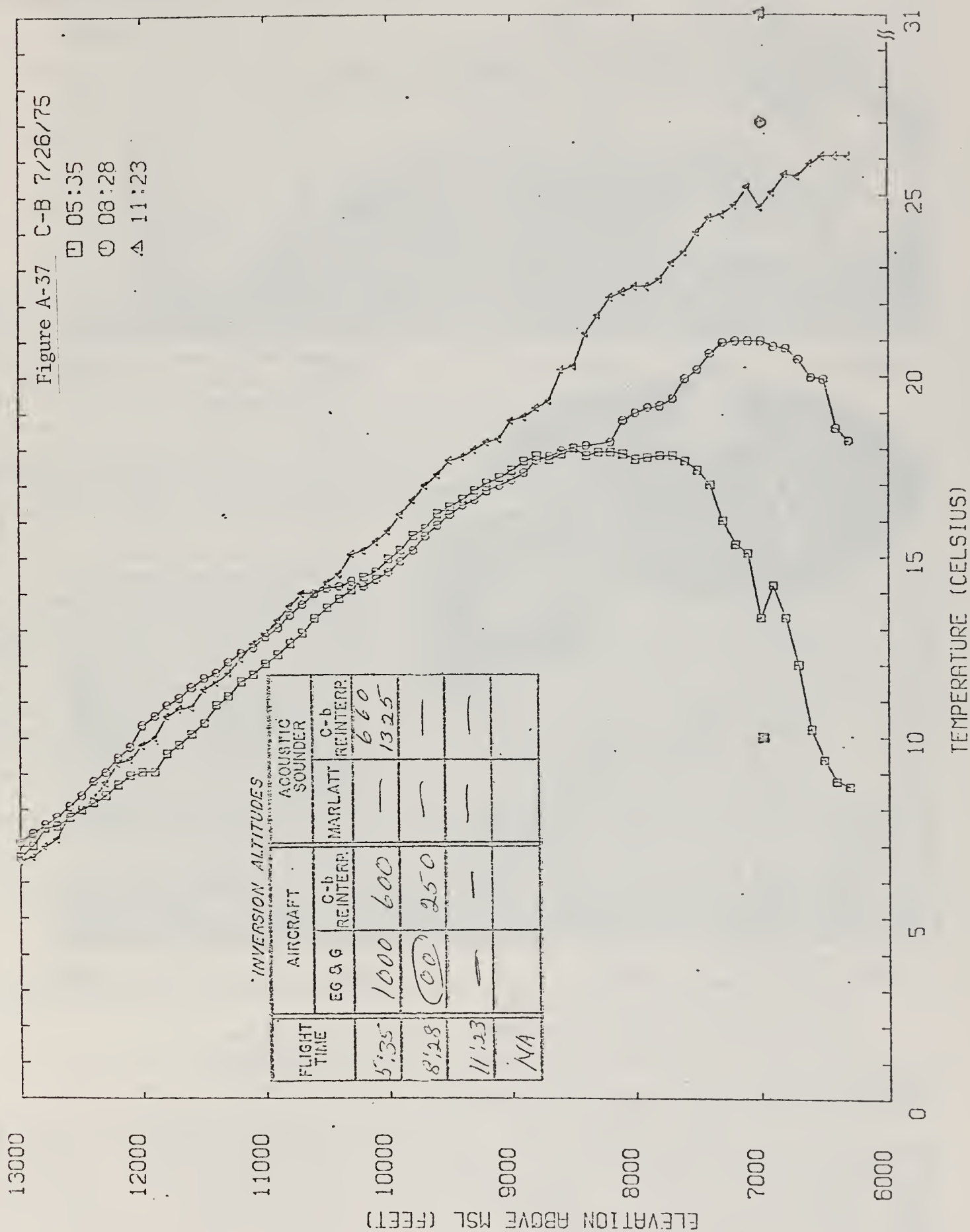


Figure A-37 C-B 7/26/75

□ 05:35
 ○ 08:28
 △ 11:23

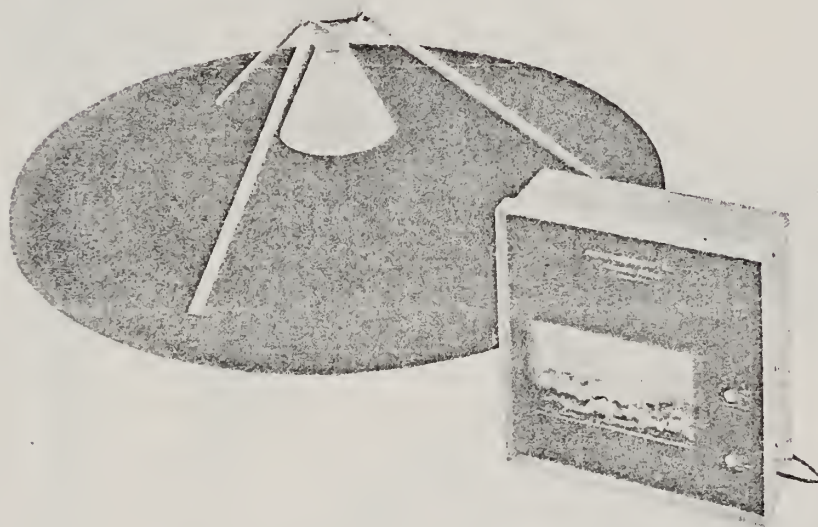




AEROENVIRONMENT INC.

145 VISTA AVE., PASADENA, CALIF. 91107 - (213) 449-4392

ACOUSTIC RADAR



The Model 300 Acoustic Radar, a monostatic acoustic sounder, provides an informative continuous cross-section of the lower atmosphere by emitting a brief pulse of sound upward, listening to the echoes which return from temperature variations aloft, and displaying the height of these echo regions on a chart.

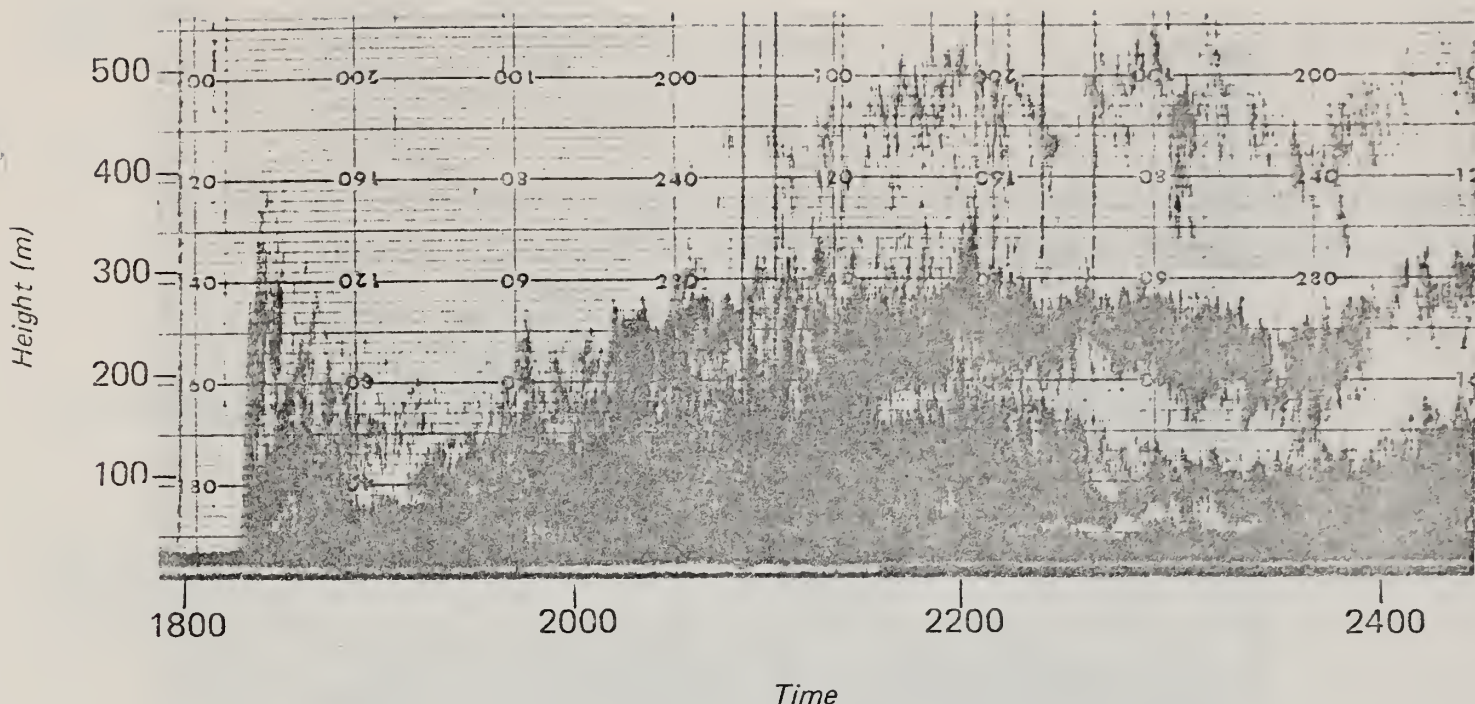
The instrument consists of 2 functional systems: (1) An electronic module which generates a short 1600 Hz electrical pulse every 7 or 14 seconds, and then amplifies the returning signal and records it on an integral time-height record by a cycling stylus; and (2) An antenna which contains an acoustic transducer to generate the sound pulse and receive the echo and a 4 foot (125 cm) parabolic reflector to focus the signal and direct it vertically. Sound scattered back from small-scale atmospheric temperature variations within the range of 1 km is recorded on a continuous chart which displays the intensity of the return echo as a function of height and time.

The Acoustic Radar gives an easily interpretable plot of the heights of atmospheric thermal structure fluctuations as a function of time. This record depicts, for example—

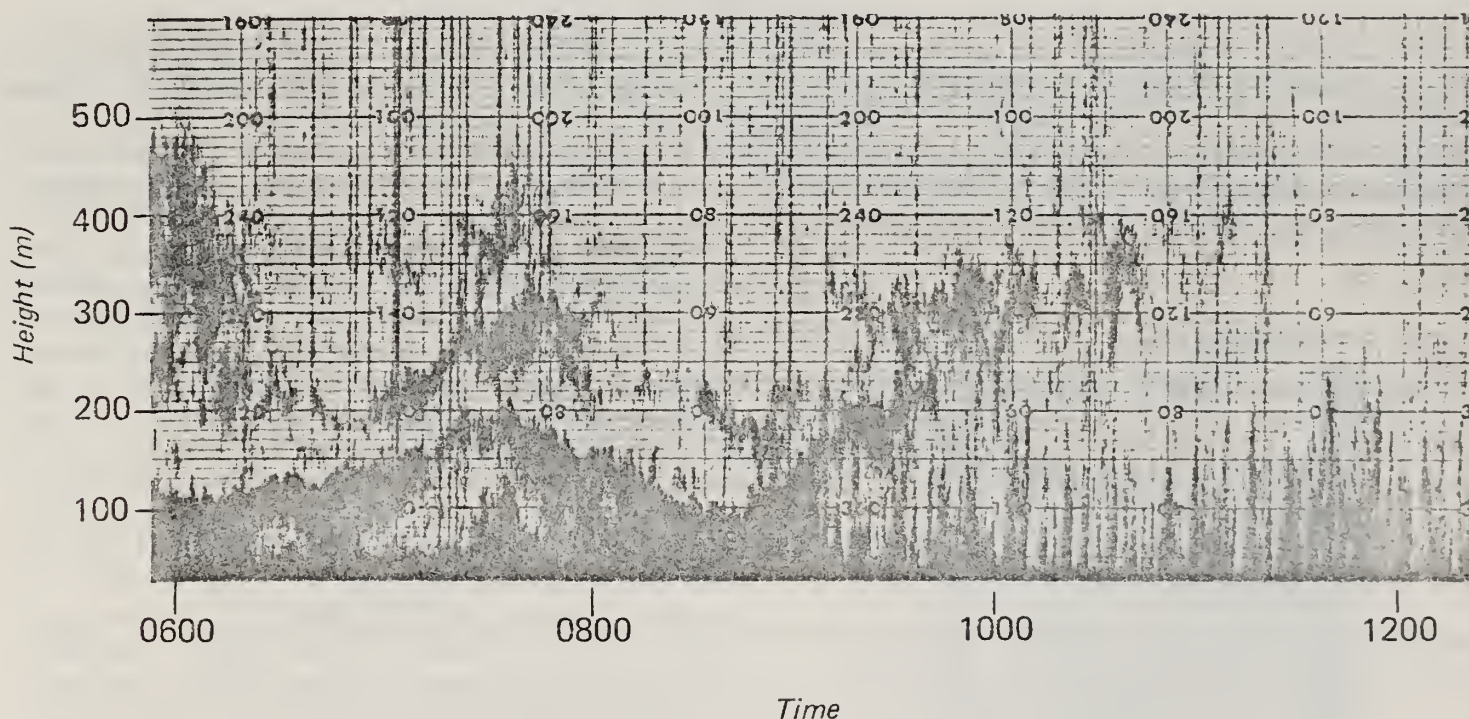
- Inversion heights and the depth of the mixing region, helping show the capability of the atmosphere to disperse pollutants
- The diurnal pattern of nocturnal layering, morning breakdown of inversions, and the daytime growth of convective cells—the timing and strength of which concern air pollution meteorologists
- Wave motions and breakdown, frontal surfaces, and marine-layer inversion, for aviation and operational meteorology, and research
- Heated plumes from smoke stacks—a direct measurement of plume rise
- The top of a layer of fog or low clouds—an operational tool for airports

Examples of some records are shown on the following pages.

The Acoustic Radar does not directly measure the temperature profile of the atmosphere, but rather records continuous information about stability, turbulence, and inversions aloft which frequently is more informative and useful than a single temperature sounding. An especially effective meteorological system is created when the Acoustic Radar is used in conjunction with rawinsonde launches or with a nearby anemometer and turbulence measurement system, in which case quantitative estimation of dispersion parameters can be carried out. Since continuous records are obtained, unattended field use of the Acoustic Radar is possible, especially when used with a mobile enclosure and battery power system.

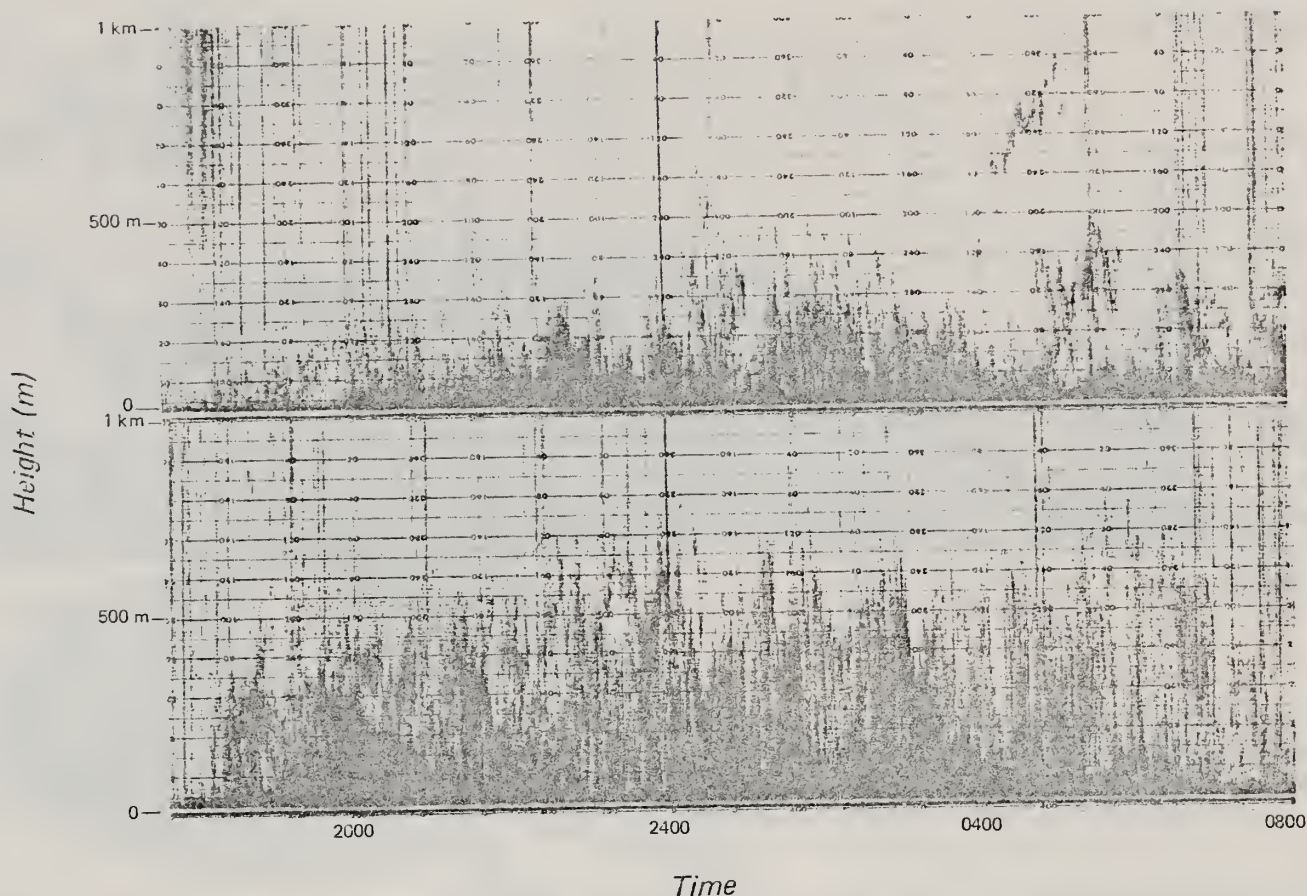


In this acoustic radar record, there is no thermal activity until 1820, when a sudden wind shift and increase in wind speed transports a front of heated desert air over the antenna. Relative calm returns by 2000 and the typical nocturnal layered structure of stable layers begins to form later on. The dark vertical lines are caused by noise from low flying jet aircraft at an adjacent airport.



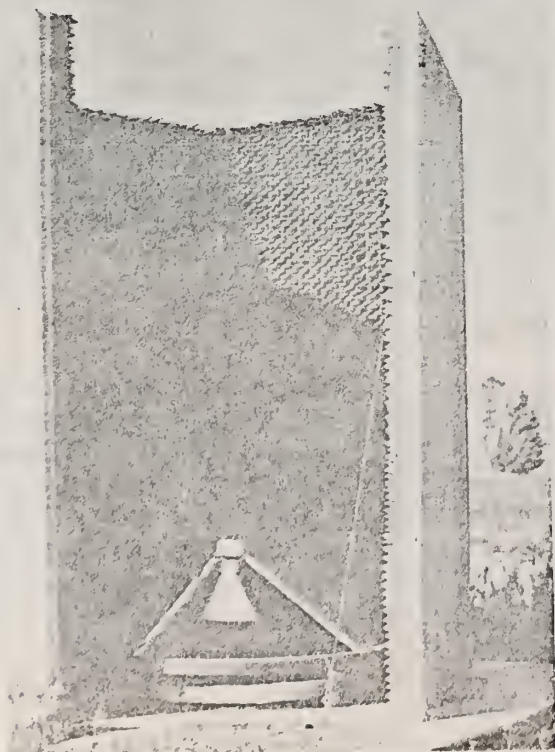
This record for the following morning shows the layered structure of the previous night being eroded from below by surface heating. The stable surface layer is lifted aloft temporarily from about 0700 to 0800 when a neutral echo-free region forms below it. Roots of thermals appear as vertical structures, starting at about 0915. The thermals drive the inversion aloft and finally penetrate it and destroy it at 1030.

Records such as the two above show when the atmosphere is unstable (vertical echo structure as at the right of the bottom chart) and when it is stable (horizontal echo structure) and indicate the heights to which such conditions extend. A detailed discussion of chart interpretation appears in AeroVironment Technical Paper 359, "Use of a Monostatic Acoustic Sounder for Air Pollution Estimates" by I. Tombach, P. MacCready, and L. Baboolal, which appears in the Proceedings of the 2nd Joint Conference on the Sensing of Environmental Pollutants, Washington D.C., 10-12 December 1973. Copies are available from AeroVironment.



A comparison of records for two consecutive winter nights. The top record shows a thin stable turbulent layer which occasionally builds up to 100-200 m depth. Little layering is observed above it except for two inversions which appear aloft soon after 0400. On the second night, there is a multiplicity of stable layers which extend up to 500-600 m, indicating considerable turbulence in the higher winds which prevailed then. The wavy nature of the layers indicates the presence of wind shear. The mixing capability of the atmosphere is considerably greater the second night than the first.

Operation of the Acoustic Radar in noisy urban environments is routine. In such conditions, an acoustic enclosure is normally required to shield the antenna from ambient noise. Such an enclosure is available as an accessory (Model 301), or it can be made by the purchaser from plans which AV provides with each Acoustic Radar. The Model 301 Acoustic Enclosure is made up of five 4'x8' (122x244 cm) panels, each of which is a sandwich of 1/2" (13 mm) fir (for structural rigidity and sound attenuation), 1/64" (0.40 mm) lead (for sound attenuation) and 4" (10 cm) thick convoluted urethane foam (to damp out internal reflections). The five panels interlock into a pentagonal enclosure which attenuates the antenna side lobes by about 20 dB, thereby suppressing incoming noise as well as making the transmitted pulse quieter to nearby people.



Model 301 Acoustic Enclosure, with one of the five sides removed to show the antenna inside.

Specifications of Model 300 Acoustic Radar

Transmitted Pulse:	Frequency — 1600 Hz Duration — selectable 50, 100, or 200 ms Power Input — 35 W Repetition Rate — 1 per 7 seconds (500 m scale) — 1 per 14 seconds (1 km scale)
Receiver:	Gain — 10^8 Gain Compensation — proportional to time of echo return, with additional adjustment possible for short ranges Bandwidth — less than 20, 40 and 80 Hz (between -3 dB points, 72 dB/octave cutoff) switch selectable Range — Selectable 1 km or 500 m full scale — Minimum 10 m Resolution — 10 m
Recorder:	Writing Technique — electric on conducting chart paper Chart size — 6" (15.2 cm) wide by 72' (22 m) Chart speed — 1.2" (3.05 cm) per hour Chart duration — 28 days
Sound Level (with Model 301 Acoustic Enclosure)	Transmitted horizontally — <60 dBA at 10 m Maximum Ambient for Operation — approximately 68 dBA for 1 km scale, 74 dBA for 500 m scale
Size and Weight:	Electronics and Recorder — 17" W x 17" H x 6" D, 45 lbs (43 cm W x 43 cm H x 15 cm D, 18 kg) Antenna and Transducer — 52" dia x 36" H, 58 lbs (133 cm dia x 80 cm H, 23 kg)
Power Input:	115V, 60 Hz, 50 W average, 250 W peak during transmittal pulse

Accessories and Optional Equipment

- Model 300, Option 001 — With 140 W power to acoustic transducer, improved signal-to-noise ratio by 6 dB (2X), for use in noisy environments
- Model 300, Option 002 — For use on 220 to 240 V power
- Model 300, Option 003 — For use on 50 Hz power
- Model 300, Option 004 — With 250 m and 500 m full scale ranges and 2.5 in/hr (6.35 cm/hr) chart speed, for use in low level diffusion studies
- Model 300, Option 005 — With 750 m and 1500 m full scale (requires that Option 001 be installed in instrument)
- Additional options are available for special applications and include 2 km full scale chart range, 500 ms pulse length, higher pulse power, and separate switching of bandwidth and pulse length.
- Part No. 300-100 — Chart Paper, 72 foot (22m) roll
- Part No. 300-101 — Rack Mount Kit for electronics and recorder
- Part No. 300-102 — Antenna Heater for melting snow and ice
- Model 301 — Acoustic Enclosure
- Model 310 — Mobil Acoustic Radar System. Consists of Model 300 Acoustic Radar, Model 301 Acoustic Enclosure, Model 600 Inverter for operation from batteries, and weather-tight cabinets for operation of system in all weather conditions, all installed on a trailer.
- Model 311 — Same as Model 310, but without Model 300 Acoustic Radar, for those who already own the Model 300
- Model 315 — Mobil Diffusion Measurement System. Consists of Model 310 Mobil Acoustic Radar System (with Option 004) with 24' (7 m) crankup tower and anemometers for wind speed, direction, and vertical turbulence.
- Model 316 — Same as Model 315, but without Model 300 Acoustic Radar, for those who already own the Model 300
- Model 600 — 12 VDC to 115 VAC, 60 Hz, Inverter for battery operation of Acoustic Radar
- Model 601 — 12 VDC to 230 VAC, 50 Hz, Inverter for battery operation of Acoustic Radar
- Model 602 — 12 VDC to 230 VAC, 60 Hz, Inverter for battery operation of Acoustic Radar for Option 001
- Model 603 — 12 VDC to 230 VAC, 50 Hz, Inverter for battery operation of Acoustic Radar for Option 001

Contact AeroVironment for information on:

- price and delivery
- rentals and leases
- applications
- custom systems and special configurations
- bibliographies on acoustic sounding
- complete meteorological and diffusion studies using the Acoustic Radar

